1973-06

Some performance characteristics of the Bell 100 ton surface effect ship

Cagle, Lonnie Francis

Monterey, California. Naval Postgraduate School

SOME PERFORMANCE CHARACTERISTICS OF THE BELL 100 TON SURFACE EFFECT SHIP

Lonnie Francis Cagle

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

SOME PERFORMANCE CHARACTERISTICS
OF THE
BELL 100 TON SURFACE EFFECT SHIP

by

Lonnie Francis Cagle

Thesis Advisor: G.J. Thaler

June 1973

Some Performance Characteristics of the Bell 100 Ton Surface Effect Ship

by

Lonnie Francis Cagle
Lieutenant Commander, United States Navy
B.S., University of California at Davis, 1960

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
June 1973

ABSTRACT

A computer program for simulating the performance of the 100-B Surface Effect Ship is used to study the longitudinal motions of the ship under various wave conditions. An investigation into the effect that waves have on bow seal, stern seal, and plenum presures is conducted. The relationship between the different pressures and their associated requirements of input air from the fans is studied. It is concluded that the computer program is limited to a certain range of speeds. The concept of the ship capturing air to reduce drag and increase its speed is questionable due to the rapid replenishment of air required to keep the ship riding on its bubble of air.

TABLE OF CONTENTS

I. INTRODUCTION -- 9

II. NATURE OF THE PROBLEM ------------------------------ 12

A. LEADING PARTICULARS -------------------------- 12

1. Dimensions ---------------------------------- 12

2. Weights ------------------------------------- 12

3. Center of Gravity --------------------------- 12

4. Propulsion ---------------------------------- 13

5. Propellers ---------------------------------- 13

6. Fans -- 13

7. Rudders ------------------------------------- 13

8. Appendages (fins) --------------------------- 13

B. COORDINATE SYSTEM ---------------------------- 14

C. WAVE AMPLITUDE ------------------------------- 15

D. COMPUTER SUBPROGRAMS ------------------------- 15

1. Main Program -------------------------------- 16

2. Subroutine AEROD ---------------------------- 16

3. Subroutine BOWSL ---------------------------- 16

4. Subroutine COLFIL --------------------------- 16

5. Subroutine DMINV ---------------------------- 17

6. Subroutine FAN ------------------------------ 17

7. Function FG1 -------------------------------- 17

8. Subroutine FORIT ---------------------------- 17

9. Subroutine INCON ---------------------------- 17

10. Subroutine INTGRL -------------------------- 18

11. Subroutine PROP ---------------------------- 18
12. Subroutine RHS ----------------------------- 18
13. Subroutine RUDDER -------------------------- 19
14. Subroutine SAM ----------------------------- 19
15. Subroutine SIDEWL -------------------------- 19
16. Subroutine STNSL --------------------------- 19
17. Functions T1 and T2 ------------------------ 20
18. Subroutine WAVES --------------------------- 20
E. EQUATIONS ------------------------------------ 20
F. NUMERICAL INTEGRATION TECHNIQUE -------------- 22
III. COMPUTER PROGRAM PROCEDURE ----------------- 23
A. PROGRAM FAMILIARITY -------------------------- 23
B. MULTIPLE CASES ------------------------------- 23
C. LIMITATIONS ---------------------------------- 23
1. Wave Components ----------------------------- 23
2. Wind -- 24
3. Speed --------------------------------------- 24
4. Water Contact with Top of Plenum ------------ 24
5. Draft --------------------------------------- 24
6. Fan Flow Rates and Fan Power ---------------- 24
D. INITIAL CONDITIONS --------------------------- 24
E. TOLERANCE VALUES OF INTEGRATORS -------------- 25
F. INITIAL PARAMETERS SELECTED ------------------ 29
1. Speed --------------------------------------- 29
2. Wave Direction ------------------------------ 29
3. Wave Length --------------------------------- 29
4. Wave Amplitude ------------------------------ 29

G. CHANGING WEIGHT ---------------------------------- 29

H. PROBLEMS ENCOUNTERED ---------------------------- 30

1. Minimum Speed ------------------------------ 30

2. Maximum Wave Amplitude --------------------- 31

3. Water Contact with Plenum ------------------ 34

4. Negative Fan Horsepower -------------------- 35

5. Problem Time Versus Computer Time ---------- 37

6. Reducing Computer Time --------------------- 37

7. Output Data Limitation --------------------- 38

IV. PRESENTATION OF DATA -------------------------------- 39

A. DRAG VERSUS SPEED ---------------------------- 39

B. STEADY-STATE SPEED --------------------------- 39

C. BOW AND SIDEWALL LEAKAGE --------------------- 44

D. PHASE RELATIONS OF VARIABLES ----------------- 44

1. Ahead Waves -------------------------------- 47

2. Astern Waves ------------------------------- 49

E. AVERAGE AND FLUCTUATION VALUES OF VARIABLES - 51

V. DISCUSSION -- 130

A. CAPTURE AIR BUBBLE CONCEPT ------------------- 130

B. WAVE CONDITIONS ------------------------------ 132

VI. CONCLUSIONS --- 133

A. PERFORMANCE ---------------------------------- 133

B. RECOMMENDATIONS ------------------------------ 134

1. Leakage Rates ------------------------------ 135

2. Air Inputs by Fans ------------------------- 135

3. Stern Seal Leakage ------------------------- 135

4. Steady-State Speed ------------------------- 136

5. Validity of Computer Data ---------------- 136

6. Additional Data -------------------------- 136

APPENDIX A: CALCULATION OF CRITICAL SPEED ------------ 137

APPENDIX B: SAMPLE INPUT DATA DECK ------------------- 140

APPENDIX C: NODAL METHOD FOR WEIGHT DISTRIBUTION ----- 145

LIST OF REFERENCES ---------------------------------- 147

INITIAL DISTRIBUTION LIST --------------------------- 148

FORM DD 1473 -- 150

TABLE OF SYMBOLS AND ABBREVIATIONS

AEROD	=	aerodynamics
BOWSL	=	bow seal
FORIT	=	fourier analysis
FXAED	=	aerodynamic force in x direction
FXBS	=	bow seal force in x direction
FXPWAV	=	bubble-type force in x direction due to drag between bubble and wave surface
FXRUD	=	rudder force in x direction
FXSS	=	stern seal force in x direction
FXSW	=	sidewall force in x direction
I_{xx}	=	mass moment of inertia about x-axis
I_{xz}	=	mass moment of inertia about xz-axis
I_{yy}	=	mass moment of inertia about y-axis
I_{zz}	=	mass moment of inertia about z-axis
INCON	=	initial condition
INTGRL	=	integral
K	=	roll moment
λ	=	length of craft (72 feet)
m	=	mass
m_b	=	mass of the air bubble
N	=	pitch moment
P=p	=	rotational velocity about x-axis
P_b	=	pressure in the bubble
PHI=ϕ	=	roll angle
PROP	=	propellar

PSF = pounds per square foot

PSI=ψ = yaw angle

Q = rotational velocity about y-axis

Q_{in} = air flow rate in

Q_{out} = air flow rate out

R = rotational velocity about z-axis

RHS = right hand side

SAM = shear and moment

SIDWL = sidewall

STNSL = stern seal

ρ_a = standard atmospheric reference

T = arbitrary steady-state time

THETA=θ = roll angle

U = longitudinal velocity

V = lateral velocity

W = vertical velocity

X = horizontal distance in direction of motion

Y = horizontal distance perpendicular to direction of motion

Z = vertical distance

I. INTRODUCTION

Conventional monohull displacement ships are limited to a maximum speed of approximately 50 knots. This is because the drag on conventional displacement ships increase exponentially with speed, resulting in a limit as to maximum economical propulsion plant that can be installed.

Many new designs of ships have been proposed over the past few years. These include the "slender body" ship, catamaran, hydrofoils, semisubmerged ships, air cushion vehicles (ACV), and surface effects ships (SES). All of these types of ships or vehicles have certain advantages and disadvantages.

One of the most promising designs in overcoming the 50 knot speed limit is the surface effect ship. The surface effect ships are usually classified as to either the Captured Air Bubble (CAB) type or the Hovercraft (GEM-Ground Effects Machine) type.

The Hovercraft design is size limited due to the inefficient use of forced air to keep the craft above the water surface. No attempt is made to "capture" the air under the craft although the design of flexible skirts around the craft have been improved in recent years to retard the leakage rate of the forced air.

The Captured Air Bubble design uses rigid sidewalls and flexible seals (bow and stern) to "capture" the forced air

in the plenum, thereby reducing the size of the machinery required to generate the input air flow. The drag created by the CAB craft is reduced considerably when the craft is operating in the "on bubble" mode. This in turn allows for a greater speed than conventional monohull ships for the same amount of thrust. The CAB is not size limited as is the case of the Hovercraft.

To date three CAB type vehicles are operational.

a. The XR-3 craft was built by David Taylor Model Basin (now designated Naval Ships Research and Development Center [NSRDC]). It has a displacement of approximately 2.5 tons. The XR-3 is presently located at the Naval Postgraduate School (NPS), Monterey, California.

b. The SES 100-A craft was built by Aerojet-General Corporation. It has a displacement of approximately 100 tons and is located at Tacoma, Washington.

c. The SES 100-B craft was built by Bell Aerospace Company with headquarters at Michoud Station, Louisiana. It has a displacement of approximately 100 tons and is presently located at Lake Pontchartrain, Louisiana. To date this craft has been run at speeds in excess of 70 knots [Ref. 1].

To better understand the motions and loads of the SES 100-B CAB, the Surface Effect Ships Project Office in Washington, D.C. issued a contract to Oceanics, Inc. of New York to write a computer program and gather certain basic data on the SES 100-B. The computer program was

completed in 1971 and a copy of the program was installed in the W.R. Church Computer Center at Monterey in October, 1972.

This investigation will concern itself only with presenting results obtained in exercising the computer program developed for the SES 100-B CAB.

In a letter to Doctor G.J. Thaler, NPS, Monterey, from Mr. S. Davis, SESPO, [Ref. 2], a list of future studies of the SES 100-B craft, using the computer program developed by Oceanics, was suggested. This author selected to study the variation of pitch, heave, and pressures in regular waves (ahead and astern) by varying ship speed, wave length, and wave height as suggested in paragraph 2a, [Ref. 2].

II. NATURE OF THE PROBLEM

A. LEADING PARTICULARS

The following is a list of the leading particulars of the SES 100-B craft.

1. Dimensions

Length, Overall	76.3 ft.
Beam, Overall	35.0 ft.
Height, Overall	27.0 ft.
Hull Length	72.0 ft.
Cushion Area	1907 $ft.^2$
Bubble Pressure	92.8 PSF
Distance Centerline to Sidewall	15.54 ft.
Plenum Length at Water Surface	65.31 ft.
Plenum Width at Water Surface	31.16 ft.
Plenum Average Height	6.17 ft.
Froude Number	0.6
Keel to Deck	13.5 ft.

2. Weights

Empty Weight	103,071 lbs
Gross Weight	209,999 lbs (105 tons)

3. Center of Gravity

Longitudinal Feet Forward of Transom	33.09 ft.
Transverse Feet to Starboard	0.0 ft.
Vertical Feet above Keel	7.09 ft.

4. <u>Propulsion</u>

Three (3) Pratt and Whitney FT 12A-6 Marine Gas Turbines. 4500 HP (each) Rated at 59°F.

5. <u>Propellers</u>

Two (2) Supercavitating CRP Marine Screws,

Diameter	3.50	ft.
Feet Forward of Transom	-1.0	ft.
Feet from Centerline to Propeller Center	15.75	ft.
Feet Above Keel	.09	ft.

6. <u>Fans</u>

Number of Bow Seal Fans	1	
Speed of Bow Seal Fans	1700	RPM
Number of Cushion Fans	5	
Speed of Cushion Fans	1700	RPM
Number of Stern Seal Fans	2	
Speed of Stern Seal Fans	1870	RPM
Maximum Total Fan Power	1187.5	HP

7. <u>Rudders</u>

Number of Rudders	2	
Feet Forward of Transom	6.125	ft.
Feet from Centerline to Rudder Centroid	15.6	ft.
Feet Above Keel	-1.5	ft.
Rudder Area (one)	6.375	$ft.^2$

8. <u>Appendages</u> (fins)

Number of Appendages	2	
Appendage Span	3.0	ft.
Appendage Chord	3.0	ft.

Distance of Appendage Centroid Forward of Transom	15.0	ft.
Distance from Centerline to Centroid of Appendage	14.875	ft.
Distance of Appendage Centroid Above Keel	-1.5	ft.
Appendage Cant Angle (positive cant angle is inboard)	30.0	deg.

B. COORDINATE SYSTEM

A body moving in a fluid can move in all six degrees of freedom of motion -- translation along each of three orthogonal axes and rotation about each of the three axes. The SES 100-B craft has a plane of symmetry (as have most ships in existence), which is defined by the ship's centerline and a line perpendicular to the ship's deck. The axis system describing the SES 100-B craft is assumed to translate with the craft and only to allow rotation of the axes about the vertical axis. With the inertial frame axes being a right handed cartesian coordinate system, represented by x_o, y_o, and z_o, with z_o positive down, and an origin selected at a reference point on the undisturbed free surface, the z-axes are identical. The ship axis system has its origin at the center of gravity of the ship with the x-axis positive toward the bow, y-axis positive to starboard, and z-axis positive downward. The relationship between the inertial reference frame and craft axis system is based upon the

values of pitch (θ), roll (ϕ), and yaw (Ψ) angles. This relationship can then be expressed [Ref. 3]

$$\begin{bmatrix} X_o \\ Y_o \\ Z_o \end{bmatrix} = \begin{bmatrix} \cos\Psi & \sin\Psi & 0 \\ -\sin\Psi & \cos\Psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \qquad (1)$$

C. WAVE AMPLITUDE

The computer program does not allow for an instantaneous build-up of wave amplitude. Instead an exponential rise in wave amplitude is used based on the formula

$$\text{wave amplitude} = 1.0 - e^{-\frac{\text{time}}{1.30287}} \qquad (2)$$

A one foot amplitude will require approximately 4.0 seconds to build up to 95 percent of maximum amplitude and approximately 6.0 seconds to build up to 99 percent of maximum amplitude. The reason for this exponential build-up of wave amplitude is that the integration routine used in the computer program cannot calculate accurately such an instantaneous jump.

D. COMPUTER SUBPROGRAMS

The computer program developed for the SES 100-B craft uses various subprograms for calculating data. These subroutines are [Ref. 4]:

1. Main Program

The main program contains the logic for interconnecting the various subroutines. It compares the running value of time with the finish time, calculates the next value of time for printing after each print time, and provides some output data. It contains the logic for integration of the trajectory (x,y,Ψ) by the trapezoidal rule.

Output is time, U, V, W, P, Q, R, Z, Phi, Theta, X, Y, Psi, sideslip angle, rudder angle, and thrust.

2. Subroutine AEROD

Subroutine AEROD calculates the aerodynamic forces and moments on the craft.

Output is aerodynamic forces and moments.

3. Subroutine BOWSL

Subroutine BOWSL calculates the forces and moments due to the bow seal and the leakage flow rate associated with any gaps under the various bow seal stations.

Output is the gap at the various stations, wetted lengths at the various stations, and forces and moments due to the bow seal.

4. Subroutine COLFIL

Subroutine COLFIL gives a tabular summary of selected variables in the vertical and/or lateral plane. A total of eight variables can be selected for each summary.

5. Subroutine DMINV

Subroutine DMINV is a matrix inversion package used for inverting the mass matrix. The method used is the standard Gauss-Jordan technique. The determinant of the matrix is also calculated.

There is no output from this subroutine.

6. Subroutine FAN

Subroutine FAN is used to calculate the inflow to the plenum from the fans for a given pressure differential across the fans.

Output is flow rates and pressure differentials across the bow seal, plenum, and stern seals.

7. Function FG1

The purpose of FG1 is to perform the task of evaluating a tabular function y = f(x). The procedure used is linear interpolation between data points.

There is no output data from function FG1.

8. Subroutine FORIT

Subroutine FORIT is used to obtain a Fourier analysis of a periodically tabulated function.

There is no output data from subroutine FORIT.

9. Subroutine INCON

Subroutine INCON contains the logic for the reading of all input data, the initialization of variables, and for the initiation of new cases.

Output is a complete listing of all initial conditions. The initial conditions will always be printed at the start of each new case.

A sample data deck for establishing initial conditions is contained in Appendix B.

10. <u>Subroutine INTGRL</u>

Subroutine INTGRL is used to integrate a system of first order ordinary differential equations. It uses a variable time step technique based on the Runge-Kutta-Merson algorithm. The program will stop the calculation if the time step becomes smaller than 10^{-6} sec.

Outputs will occur when the calculated error is greater than the tolerance set on that particular integrator. Output format contains time, integrator step size (DELT), integrator number (J), error value, and tolerance value.

11. <u>Subroutine PROP</u>

Subroutine PROP calculates the forces and moments on the craft due to the propulsion system. The port engine is always assumed to be the engine which fails if an engine out is designated.

Output is the propulsion forces and moments.

12. <u>Subroutine RHS</u>

Subroutine RHS contains the FORTRAN expressions for the right hand side of the system of first order differential equations.

Output consists of plenum pressure, fan power required, fan flow rate, leakage flow rates for bow, sidewall, and stern seals, plenum area and volume, total forces and moments, bow and stern accelerations, and an array of values of the right hand side of the differential equations.

13. Subroutine RUDDER

Subroutine RUDDER calculates the forces and moments on the rudder as well as the rudder motions.

Output is the forces and moments on the rudder.

14. Subroutine SAM

Subroutine SAM performs all the processing and calculations involving determination of shears and moment.

This subroutine was not required to be used in obtaining the data contained in this report.

15. Subroutine SIDEWL

Subroutine SIDEWL calculates the forces and moments due to the sidewalls as well as the leakage flow rates associated with any gaps under the sidewalls. The subroutine also contains the logic for the forces and moments due to the appendages (fins).

Output is the gap and immersion depth at designated stations along port and starboard sidewalls and also the forces and moments due to the sidewalls.

16. Subroutine STNSL

Subroutine STNSL calculates the forces and moments acting on the craft due to the stern seal as well as the

leakage flow rates arising from any gaps which open under the seal.

Output is gap and stern seal wetted lengths at various stations across the stern seal in addition to forces and moments arising from the stern seal.

17. Functions T1 and T2

Functions T1 and T2 are two function subroutines used to calculate various trigonometric relations used by subroutine WAVES.

There is no output data from Functions T1 and T2.

18. Subroutine WAVES

Subroutine WAVES calculates the wave forces and moments acting on the craft. It also generates the wave amplitudes at various stations around the seals and sidewalls, as well as bubble volume lost due to wave elevation. The sea state for irregular seas is computed by adding together a series of regular waves with an appropriate distribution of amplitude and frequency.

Output is the wave elevations relative to calm water at the various stations around the bow seal, stern seal, port and starboard sidewalls. Also the wave elevation at the center of gravity, plenum volume lost due to waves, and wave forces and moments are listed.

E. EQUATIONS

The ten (10) first order ordinary differential equations derived [Ref. 3] for use by a digital computer are:

$$\dot{u} = mx \tag{3}$$

$$\dot{v} = my - mur \tag{4}$$

$$\dot{w} = mz \tag{5}$$

$$\dot{p} = I_{xx}K - I_{xz}N \tag{6}$$

$$\dot{q} = I_{yy}M \tag{7}$$

$$\dot{r} = -I_{xz}K + I_{zz}N \tag{8}$$

$$w = \dot{z} \tag{9}$$

$$p = \dot{\phi} \tag{10}$$

$$q = \dot{\theta} \tag{11}$$

$$\dot{m}_b = \rho_a(Q_{in} - Q_{out}) \tag{12}$$

In addition three (3) auxiliary equations [Ref. 3] are used. These are

$$x = \int_o^t u\ dt \tag{13}$$

$$y = \int_o^t v\ dt \tag{14}$$

$$\Psi = \int_o^t r\ dt \tag{15}$$

Since the variables x, y, and Ψ defined in Equations (13) - (15) are expected to have (in general) slow variation

and do often extend to large values, Simpson's Rule Technique is used for integration in the Main Program section.

Equations (3) - (12) use the Runge-Kutta-Merson method of integration. A tolerance level is selected for each of these equations. A truncation error, ε, is calculated. If any element in ε > tolerance level, then the trial time step size previously selected is halved and the computations are repeated for that time step. If all elements of $\varepsilon \leq 1/16$ tolerance, the step size is then doubled in the next integration step. Otherwise the computations proceed using the same step size for the next calculations.

F. NUMERICAL INTEGRATION TECHNIQUE

There are many integration schemes to choose from for a general system simulation where speed and accuracy is of paramount importance. The Runge-Kutta-Merson method was selected [Ref. 3].

III. COMPUTER PROGRAM PROCEDURE

A. PROGRAM FAMILIARITY

The first priority in using the computer program developed by Oceanics, Inc. was to become familiar with the various subroutines and to determine the limitations of the program. Very little data is available at present on the performance of the SES 100-B; either through computer simulation or actual craft tests. Since the computer program was installed at NPS, Monterey in October, 1972, this author was one of the first persons to use the program installed in the NPS 360/67. As a result, this author was like a growing lad; first learning to crawl, then walk, and finally to run as more and more knowledge was obtained regarding the computer program.

B. MULTIPLE CASES

When making multiple cases (runs) using one data deck, all control statements not specified for that particular case will carry the values of the specified data from the previous control statement over into the next case.

C. LIMITATIONS

The limitations that were determined [Ref. 4] prior to use of the computer program were

1. Wave Components

The maximum number of wave components that can be used is ten (10).

2. Wind

No provision is made in the computer program for inputing wind direction and wind speed.

3. Speed

The minimum speed that can be used is the hump speed (16.32 kts) which is where the craft goes into the "on bubble" mode.

4. Water Contact with Top of Plenum

No provision is made in the computer program for calculating the effect of water striking the top of the plenum. The program does print the time, immersion depth, and location along sidewall where this water contact does occur.

5. Draft

The range of drafts must be selected so that the top of the plenum does not sink below the water surface. For the SES 100-B, a maximum draft of 6.17 feet is allowed.

6. Fan Flow Rates and Fan Power

Fan flow rates and the associated fan power required to produce the fan flow rates are considered to be instantaneous values. No delay times are used in the computer program when fan power and fan flow rates are changed in value.

D. INITIAL CONDITIONS

The first data that must be obtained is the initial conditions for various speeds under calm water conditions.

No waves are used so control statement 01102 (see Appendix B) is omitted. In addition the speed is a constant input and the thrust is allowed to vary by placing a one (1.0) in columns 26-35 of control statement 00105 (see Appendix B). To insure that calm water steady-state conditions are reached, the problem time should run to at least 40 seconds. The initial steady-state variables that are required as output data are draft, pitch angle, plenum pressure, and thrust. This data can be obtained by placing a one (1) in block 15, 35, and 55 on the IBM card following control statement 00102 (see Appendix B). This data could be made part of the variables printed under the vertical and lateral plane summaries of control statement 00104 (see Appendix B). The initial condition values obtained are shown in Table I. The ratio of problem time to computer time was found to be 1:0.8 for establishing initial conditions.

To check to see if initial conditions are correct, a zero (0.0) is placed in blank 26-35, or leave blank, of control statement 00105. A blank is considered a zero in the computer problem. This establishes the value of thrust as initial condition and allows the speed to vary. The values of the initial condition variables should not change with time if the initial conditions are selected correctly.

E. TOLERANCE VALUES OF INTEGRATORS

The next item that must be established is the tolerance value to be assigned to each integrator. The recommended

TABLE I

INITIAL CONDITIONS

(AS DETERMINED UNDER CALM WATER CONDITION)

SPEED (KTS)	U (FT/SEC)	DRAFT (FT)	DRAFT (IN)	THETA (DEG)	THRUST ONE ENG (LBS)
16.5	27.87	1.420	17.04	0.09	8170.8
20.0	33.78	1.406	16.87	0.12	6490.6
25.0	42.22	1.381	16.57	0.15	5314.9
30.0	50.67	1.351	16.21	0.18	4882.7
32.5	54.89	1.334	16.01	0.19	4832.4
33.0	55.73	1.330	15.96	0.20	4832.3
35.0	59.11	1.315	15.78	0.21	4860.2
40.0	67.56	1.272	15.26	0.23	5091.4
45.0	76.01	1.223	14.68	0.26	5490.2
50.0	84.45	1.166	13.99	0.28	6002.1
55.0	92.90	1.103	13.24	0.31	6589.3
60.0	101.33	1.033	12.40	0.33	7220.5
65.0	109.81	0.956	11.47	0.35	7872.8
70.0	118.22	0.874	10.49	0.36	8521.1
75.0	126.70	0.786	9.432	0.38	9147.1
80.0	135.11	0.694	8.33	0.39	9731.7
85.0	143.61	0.598	7.176	0.39	10254.3
90.0	152.0	0.498	5.98	0.40	10697.3

Note: Plenum pressure of 92.80 PSF is used as initial condition for all speeds.

procedure [Ref. 4] was to set all values to the order of 10^{-5} to 10^{-9}. Then half the value of one tolerance, rerun the program, and compare output data values. If the results do not change drastically, then double the tolerance again. As changes are noted in the integrator outputs, hold the tolerances for those integrators fixed and vary other tolerances until the largest tolerances possible are obtained.

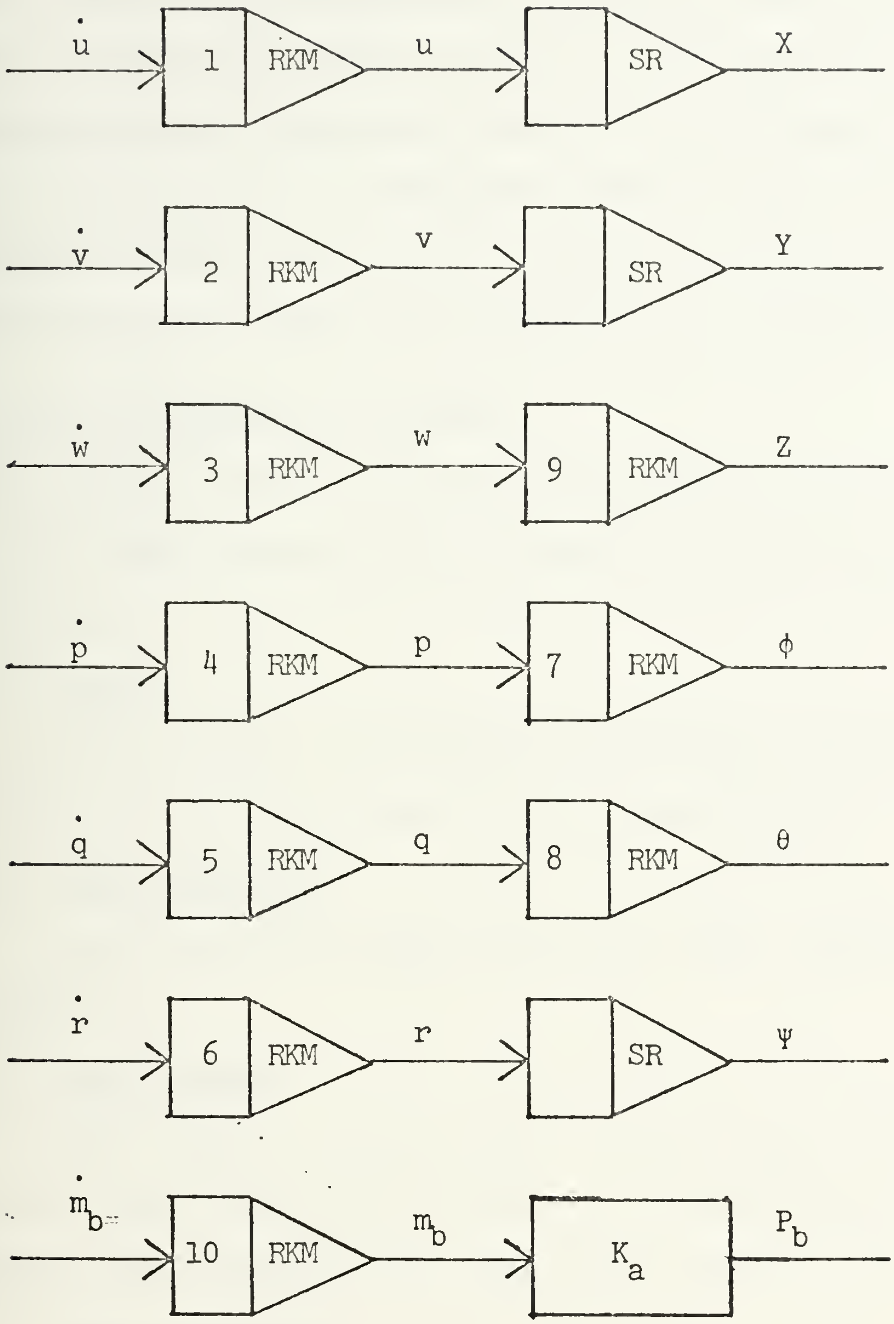
The inputs and output of each integrator are shown in Fig. 1. Since simulation runs were made into or with waves on a steady course, it was found that integrators number three (3) and ten (10) caused the greatest change in output data for a factor of ten (10) change in their tolerance.

The selected values of tolerances for each integrator that were used in all computer simulation runs are listed in Table II.

TABLE II

TOLERANCE VALUES FOR INTEGRATORS

INTEGRATOR NUMBER	TOLERANCE VALUE
1	.0001
2	.0002
3	.000001
4	.0000001
5	.0001
6	.000001
7	.000000001
8	.000000001
9	.0001
10	.0001



RKM = Runge-Kutta-Merson Method

SR = Simpson's Rule

Figure 1. Inputs and Outputs of Integrators

The values of the tolerances listed in Table II gave output data that had less than one (1) percent difference in values when the tolerance values were decreased by a factor of ten (10). If integrator number three (3) or ten (10) was increased in value by a factor of ten (10), the output data would change by as much as six (6) percent.

F. INITIAL PARAMETERS SELECTED

The desired range of parameters initially selected to obtain the data requested by paragraph 2a [Ref. 2], are listed below.

1. Speed

Speed ranges of 30 knots to 90 knots were initially selected in 10 knot increments to be investigated.

2. Wave Direction

Waves directly ahead and astern were selected to be investigated.

3. Wave Length

Wave lengths from one-half lamda ($1/2\lambda$) to five lamda (5λ) were initially selected to be investigated. λ is equal to the length of the SES 100-B which is 72.0 feet.

4. Wave Amplitude

Wave amplitudes from 1 foot to 6 feet were initially selected to be investigated.

G. CHANGING WEIGHT

Symmetry of weight distribution is assumed between port and starboard side of the SES 100-B when using the computer

program. A nodal method is used to specify the weight and center of gravity of each node. Control statement 00202 is used with the nodal method. Appendix C lists the various input values for the nodal distribution of weight and center of gravity.

If additional weight is to be added to the craft, the value of the weight to be added should be halved since symmetry is used. The value used as input will only represent that amount added to the starboard side. The center of gravity specified will be the same distance to starboard as to port.

Control statement 00201 uses the overall weight, center of gravity, and mass movement of inertia about x-axis, y-axis, z-axis, and xz-axis.

Even though control statement 00201 uses only one IBM card, as compared to the numerous cards used with control statement 00202 (see Appendix C), it was found from numerous computer runs that the computer time decreased by approximately 10 percent when control statement 00202 was used.

H. PROBLEMS ENCOUNTERED

1. Minimum Speed

The first problem encountered in using the computer program for the SES 100-B was that the longitudinal velocity (U) did not reach a steady-state value when waves were used at a speed of 30 knots. Varying wave lengths from 36 feet ($\frac{1}{2}\lambda$) to 360 feet (5λ) and wave amplitudes from

0.01 feet to 1.0 foot at a speed of 30 knots caused the longitudinal velocity to decrease exponentially as $1-e^{time}$ until hump speed was reached. This result showed that the longitudinal acceleration did not go to zero in order for the longitudinal velocity (U) to reach a steady-state condition.

An investigation into the various forces in the x-direction was conducted. Table III is a list of the calm water force components in the x-direction for various speeds. Force component FXPWAV decays exponentially as $e^{-1.56}$ with an increase in speed. The other force components (FXBS, FXSS, FXSW, FXRUD, FXAED) increase as U^2 with an increase in speed. FXP and Thrust are equal and opposite in value and represent the sum of all the forces in the x-direction. A plot of FXPWAV and the other forces in the x-direction versus speed (Fig. 2) shows that the cross-over occurs at approximately 34.0 knots.

An investigation into the minimum critical speed (U_{oc}) was conducted (see Appendix A) with the result that U_{oc} was approximately equal to 31.0 knots. This result agrees fairly well with the cross-over of the $e^{-1.56}$ and U^2 forces. Based on these results, the minimum speed used to obtain the output data was established at 35 knots.

2. Maximum Wave Amplitude

A 2 foot amplitude (height) wave is the same as a 4 foot high wave measured peak to trough. Wave amplitudes of 6 and 8 feet were tried. In this particular case, the

TABLE III

BREAKDOWN OF FORCES

(All Values in lbs)

SPEED (KTS)	FXBS	FXSS	FXSW	FXRUD	FXAED	FXPWAY
16.5	172.4	104.6	795.6	117.2	116.3	15036.0
20.0	240.5	148.3	1130.2	166.1	170.8	11125.0
25.0	351.6	221.6	1694.1	250.7	266.9	7845.0
30.0	476.4	305.4	2349.7	352.0	384.3	5897.5
34.0	583.2	378.9	2933.3	445.1	493.7	4847.6
34.5	596.8	388.5	3009.5	457.4	508.3	4738.0
35.0	610.5	398.0	3086.3	470.0	523.1	4632.5
40.0	749.0	497.0	3890.5	604.3	683.3	3758.6
50.0	1018.5	702.1	5644.1	921.6	1067.7	2650.3
60.0	1238.1	891.5	7478.9	1302.9	1537.7	1991.8
70.0	1357.4	1028.8	9250.4	1747.5	2093.5	1564.4
80.0	1321.3	1070.8	10812.0	2254.8	2735.2	1269.0
90.0	1062.6	968.0	12023.0	2823.6	3462.1	1055.3

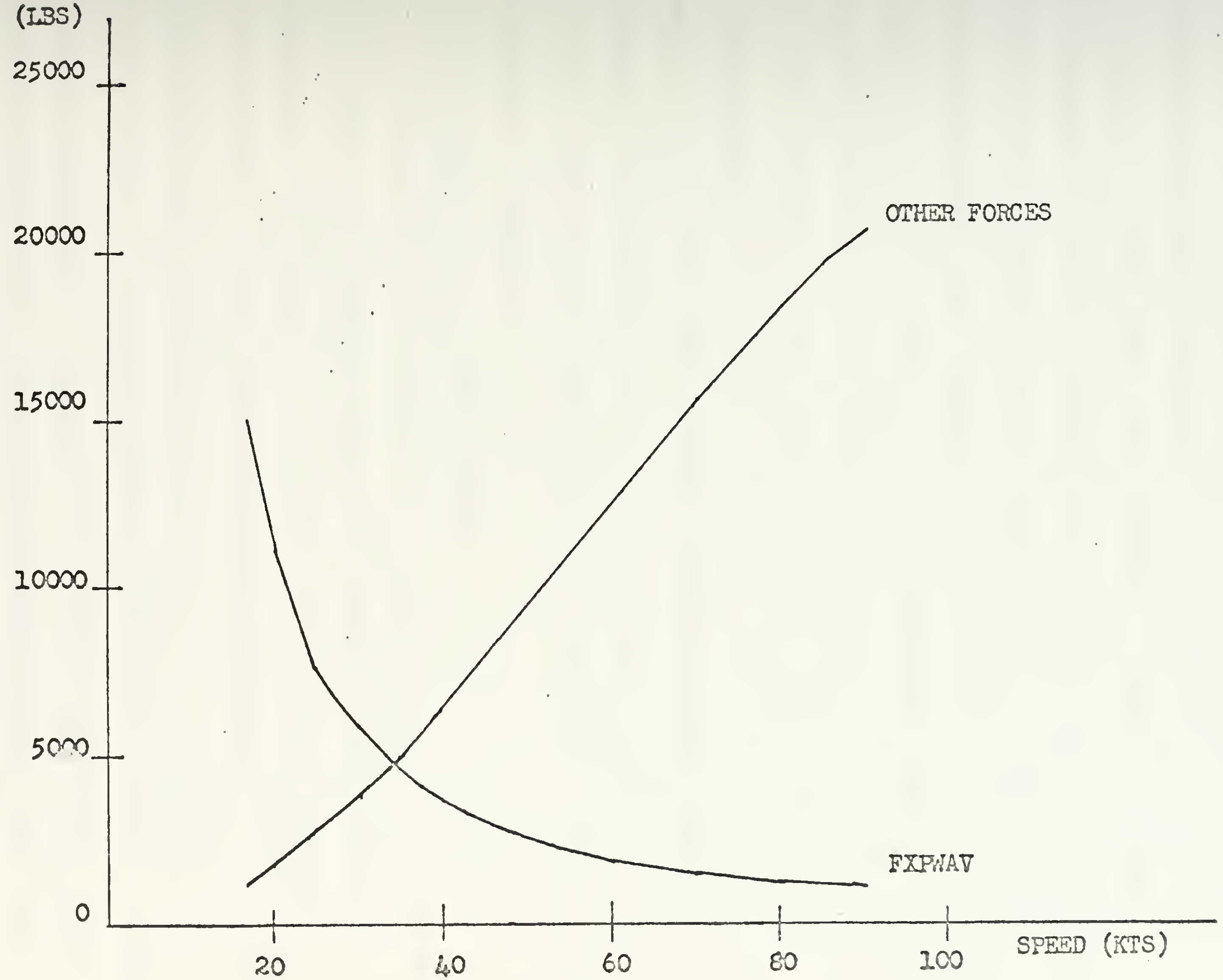


Figure 2. Force Versus Speed for Calm Water Condition

computer program would stop in approximately 7 to 11 seconds of problem time due to the size of the incremental integrator step size becoming smaller than 1×10^{-6} seconds. Varying the tolerance values assigned to each integrator would not eliminate this condition. The result is that the Runge-Kutta-Merson method of integration is restricted to a certain range of wave lengths and wave amplitudes in order that the error generated, when compared with tolerance values, be such that the incremental step size of integration would be halved, but not halved until the incremental step size was less than 1×10^{-6} seconds. Some limits of speed, wave length, and wave amplitude are given in Table IV, for both ahead and astern waves, where the computer program stopped due to the incremental integrator step size becoming less than 1×10^{-6} seconds. In every case, this condition occurred as a result of integrator number 3.

3. Water Contact with Plenum

The computer progarm will print out the time, immersion depth, and location along the sidewall whenever the amplitude of the wave would strike the top of the plenum. No provision is made in the computer program to account for the additional forces created by the wave striking the top of the plenum. It was assumed that immersion depths of only several inches above the top of the plenum would have very little effect on the performance of the craft. Since the top of the plenum is 6.17 feet above the keel, immersion depths equal to or less than 6.6 feet were considered as

having negligible effect. Data obtained where the immersion depth was greater than 6.6 feet was considered invalid. Some limits of speed, wave length, and wave amplitude are given in Table IV for both ahead and astern waves.

4. Negative Fan Horsepower

Total fan horsepower is calculated based on the amount of fan inflow rate into the bow seal, plenum, and stern seal. Under certain wave conditions, a negative fan inflow rate was indicated for either the bow seal, plenum, or stern seal. Normally the total fan inflow rate would range from 3,000 cubic feet per second to 10,000 cubic feet per second. Several different computer output runs indicated that the fan inflow rates to the bow seal would vary between 1,000 cubic feet per second to -100 cubic feet per second. This small amount of negative fan inflow rate, when compared to the large net positive value of total fan inflow rate, was considered not sufficient to alter the output data. When the net total fan inflow rate was negative, which normally requires a negative fan inflow to all three locations, a negative total fan horsepower resulted. Since the fans can not be put in reverse (pumping air out), this condition was considered severe enough to cause the output data to be invalid. Some limits of speed, wave length, and wave amplitude, for both ahead and astern waves, are listed in Table IV where negative fan horsepower resulted.

TABLE IV

NON-USABLE PARAMETERS

Initial Speed (KTS)	Wave Direction	Wave Length (FT)	Wave Amplitude (FT)	Reason
75.0 (and larger)	Ahead	108.0	1.0	Negative Fan Horsepower
60.0 (and larger)	Ahead	36.0	2.0	Negative Fan Horsepower
40.0 (and larger)	Ahead	36.0	3.0	Negative Fan Horsepower
35.0 (and larger)	Ahead	360.0	3.0 (and larger)	Program Stopped due to Integrator Step Size Less than $1x10^{-6}$
35.0 (and larger)	Ahead	108.0	4.0 (and larger)	Program Stopped due to Integrator Step Size Less than $1x10^{-6}$
35.0 (and larger)	Ahead	36.0	5.0 (and larger)	Program Stopped due to Integrator Step Size Less than $1x10^{-6}$
60.0 (and larger)	Ahead	108.0	2.0 (and larger)	Negative Fan Horsepower
40.0 (and less)	Astern	108.0	1.0	Immersion Depth Larger than 6.6 Feet
75.0 (and larger)	Astern	36.0	2.0 (and larger)	Negative Fan Horsepower
50.0 (and less)	Astern	36.0	4.0	Immersion Depth Larger than 6.6 Feet

5. Problem Time Versus Computer Time

The ratio of problem time to computer time for a 1 foot amplitude wave was found to be approximately 1:40. Increasing wave length and speed increased this ratio very slightly (1:42). This ratio holds good for both ahead and astern waves, with just a slight decrease in the ratio for astern waves (1:38). Increasing the wave amplitude from 1 to 2 feet would change the ratio from 1:40 to 1:60. Increasing the wave amplitude from 1 to 3 feet would change the ratio from 1:40 to 1:70.

6. Reducing Computer Time

It was found that using the calm water initial conditions would require approximately 140 to 160 seconds for the value of U to reach a steady-state condition. With an additional 10 to 20 seconds added for printing out steady-state values, a total of 2.0 to 3.0 hours of computer time was required for each combination of speed, wave direction, wave length, and wave amplitude.

To reduce the computer time required, a run of 40 seconds problem time was used with the initial calm water conditions as input values. The value of U obtained for each run was plotted between 0 and 40 seconds and an estimate of steady-state speed (U) was made. This steady-state speed (U) could be estimated because the speed (U) would decrease exponentially with time from its calm water value as waves were encountered. The new estimated steady-state speed (U) was then used in control statement 01201 as a new

initial speed, and the program was run for an additional 30 seconds. This resulted in a reduction of 1.0 to 1.5 hours of computer time for each parameter of speed, wave direction, wave length, and wave amplitude used.

7. Output Data Limitation

The IBM-360/67 computer at the W.R. Church Computer Center has a built-in limitation as to the maximum number of pages of output data that can be obtained. A rule of thumb used was that a maximum of 100 time intervals of data could be printed out if all the print switches listed under control statement 00102 were ON (indicated by a 1.0).

IV. PRESENTATION OF DATA

A. DRAG VERSUS SPEED

A plot of drag versus speed under calm water conditions is shown in Fig. 3. The results show that a minimum value (saddle point) in the curve occurs at a speed between 32.5 and 33.0 knots. Comparing Fig. 3 with the results reported in Ref. 5, close agreement does exist between the value of hump speed and the value of drag occurring at hump speed. Figure 3 shows that the minumum value of drag occurs at a lower speed and that this particular value of drag is less than that reported in Ref. 5.

Figure 3 indicates that once hump speed is reached and the craft goes "on the bubble", it would accelerate from 16.5 knots to approximately 68 knots under calm water conditions if the value of thrust was held constant. Reference 5 indicated that the craft would accelerate from hump speed to a speed of approximately 40 knots if the value of thrust was held constant.

B. STEADY-STATE SPEED

Each particular wave condition resulted in a different steady-state speed being obtained. Table V lists the steady-state speeds that were obtained from various wave directions, wave lengths, and wave amplitudes. Although the steady-state value of speed is only valid for the particular wave condition listed, the values are useful in estimating other

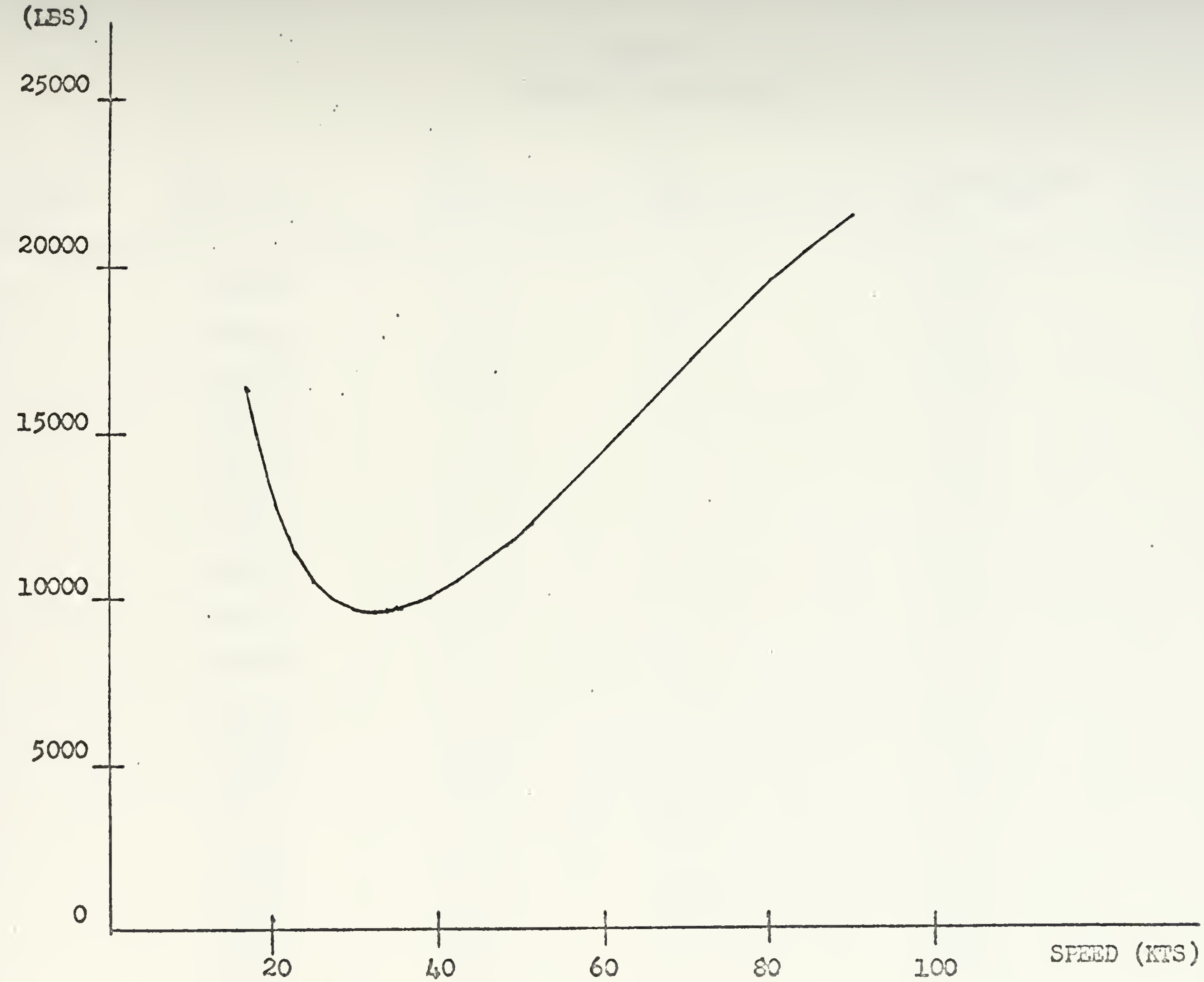


Figure 3. Drag Versus Speed for Calm Water Condition

TABLE V

STEADY-STATE SPEEDS

Initial Speed (KTS)	Wave Direction	Wave Length (FT)	Wave Amplitude (FT)	Steady-State Speed (KTS)	Fluctuation Steady-State Speed (KTS)
35.0	Ahead	36.0	1.0	30.84	0.04
35.0	Ahead	72.0	1.0	34.70	0.02
35.0	Ahead	108.0	1.0	28.81	0.21
35.0	Ahead	36.0	2.0	27.36	0.04
40.0	Ahead	36.0	1.0	36.12	0.02
40.0	Ahead	72.0	1.0	39.61	0.03
40.0	Ahead	108.0	1.0	35.47	0.21
40.0	Ahead	36.0	2.0	32.92	0.04
40.0	Ahead	72.0	2.0	34.05	0.03
40.0	Ahead	108.0	2.0	28.46	0.37
50.0	Ahead	36.0	1.0	44.85	0.03
50.0	Ahead	72.0	1.0	49.20	0.02
50.0	Ahead	108.0	1.0	42.95	0.16
50.0	Ahead	36.0	2.0	38.58	0.04
60.0	Ahead	36.0	1.0	52.29	0.02
60.0	Ahead	72.0	1.0	57.65	0.02
60.0	Ahead	108.0	1.0	49.59	0.18
60.0	Ahead	72.0	2.0	48.83	0.06

TABLE V (Continued)

Initial Speed (KTS)	Wave Direction	Wave Length (FT)	Wave Amplitude (FT)	Steady-State Speed (KTS)	Fluctuation Steady-State Speed (KTS)
75.0	Ahead	36.0	1.0	61.19	0.02
75.0	Ahead	72.0	1.0	64.43	0.04
90.0	Ahead	36.0	1.0	66.69	0.02
90.0	Ahead	72.0	1.0	75.98	0.04
35.0	Astern	36.0	1.0	33.66	0.04
35.0	Astern	72.0	1.0	34.59	0.05
35.0	Astern	36.0	2.0	29.52	0.06
40.0	Astern	36.0	1.0	38.45	0.03
40.0	Astern	72.0	1.0	39.77	0.05
40.0	Astern	36.0	2.0	34.72	0.09
50.0	Astern	36.0	1.0	46.53	0.02
50.0	Astern	72.0	1.0	49.16	0.05
50.0	Astern	108.0	1.0	40.07	0.28
50.0	Astern	36.0	2.0	42.47	0.04
50.0	Astern	36.0	3.0	37.76	0.19
60.0	Astern	36.0	1.0	53.78	0.03
60.0	Astern	72.0	1.0	57.99	0.05
60.0	Astern	108.0	1.0	50.48	0.14
60.0	Astern	144.0	1.0	50.45	0.17

TABLE V (Continued)

Initial Speed (KTS)	Wave Direction	Wave Length (FT)	Wave Amplitude (FT)	Steady-State Speed (KTS)	Fluctuation Steady-State Speed (KTS)
60.0	Astern	216.0	1.0	52.20	0.72
60.0	Astern	36.0	2.0	50.36	0.04
75.0	Astern	36.0	1.0	63.11	0.04
75.0	Astern	72.0	1.0	68.67	0.06
75.0	Astern	108.0	1.0	63.23	0.27
90.0	Astern	36.0	1.0	69.92	0.03
90.0	Astern	72.0	1.0	77.04	0.12
90.0	Astern	108.0	1.0	70.13	0.30

steady-state speeds under wave conditions that are not listed. This will reduce computer usage time if the procedure listed in Paragraph III H-6 is followed.

C. BOW AND SIDEWALL LEAKAGE

Under certain wave conditions, air leakage would occur from the bow and/or sidewalls. Of course this is in addition to the stern leakage that occurs under all sea conditions. To better understand when leakage from the bow and/or sidewall did occur, Table VI lists the steady-state craft speed, wave direction, wave length, and wave amplitude when this leakage occurred.

D. PHASE RELATIONS OF VARIABLES

To help understand how the simulated motions of the craft would respond to varying wave conditions, a phase comparison of selected variables with respect to wave motion was conducted. It was found that changing the speed of the craft did not alter the phase relation between the selected variables and the particular wave used under both ahead and astern wave directions. In addition, changing the wave amplitude did not alter the phase relation between the selected variables and the particular wave used under both ahead and astern wave directions. A representative initial condition speed of 60 knots was selected to show the phase relation between the different variables with respect to various wave lengths.

TABLE VI

OCCURRENCE OF BOW AND/OR SIDEWALL LEAKAGE

Steady-State Speed (KTS)	Wave Direction	Wave Length (FT)	Wave Amplitude (FT)	Bow Leakage	Sidewall Leakage
57.65	Ahead	72.0	1.0	Yes	No
64.43	Ahead	72.0	1.0	Yes	No
75.98	Ahead	72.0	1.0	Yes	Yes
28.81	Ahead	108.0	1.0	Yes	No
35.47	Ahead	108.0	1.0	Yes	No
27.36	Ahead	36.0	2.0	Yes	Yes
32.92	Ahead	36.0	2.0	Yes	No
34.05	Ahead	72.0	2.0	Yes	Yes
48.83	Ahead	72.0	2.0	Yes	Yes
34.59	Astern	72.0	1.0	Yes	No
39.77	Astern	72.0	1.0	Yes	No
49.16	Astern	72.0	1.0	Yes	No
57.99	Astern	72.0	1.0	Yes	Yes
68.67	Astern	72.0	1.0	Yes	Yes
77.04	Astern	72.0	1.0	Yes	Yes
40.07	Astern	108.0	1.0	Yes	No
50.48	Astern	108.0	1.0	Yes	No
63.23	Astern	108.0	1.0	Yes	No
70.13	Astern	108.0	1.0	Yes	No

TABLE VI (Continued)

Steady-State Speed (KTS)	Wave Direction	Wave Length (FT)	Wave Amplitude (FT)	Bow Leakage	Sidewall Leakage
50.45	Astern	144.0	1.0	Yes	No
52.20	Astern	216.0	1.0	Yes	Yes
29.52	Astern	36.0	2.0	Yes	Yes
34.72	Astern	36.0	2.0	Yes	Yes
42.47	Astern	36.0	2.0	Yes	Yes
37.76	Astern	36.0	3.0	Yes	Yes

The variables that have been selected for study, based on Ref. 2 are: Draft, Plenum Pressure, Bow Acceleration, Center of Gravity Acceleration, Bow Seal and Sidewall Leakage Rates (where applicable), Stern Seal Leakage Rate, Input Fan Flow Rates (bow, plenum, stern), and Total Fan Horsepower.

1. Ahead Waves

Wave lengths of 36 feet (1/2 λ), 72 feet (λ), and 108 feet (3/2 λ) are shown in Figs. 4 through 24.

Figures 4, 5, and 6 show that the response of the center of gravity acceleration leads the wave for a wavelength of 36 feet and lags the wave for wavelengths of 72 and 108 feet. The smallest magnitude of center of gravity acceleration occurs for the 72 foot wavelength. Figures 7, 8, and 9 show that the bow acceleration is in phase with the center of gravity acceleration and its magnitude is larger. This is to be expected for a rigid type ship.

The average draft response is shown in Figs. 10, 11, and 12. No distinct phase relationship exists since the values of draft are averaged along the length of the sidewall. Plenum pressure is the primary determinant in establishing average draft values. The higher the plenum pressure, the smaller the average draft value that will occur. The 72 foot wave length has the smallest draft with the corresponding largest plenum pressure (see Fig. 14).

Figures 13, 14, and 15 show the response of plenum pressure to different wave lengths. Pressure in the plenum

is primarily based on the plenum volume and the difference between the air flow in and out of the plenum. As the volume is decreased (increase in draft), the plenum pressure will increase. Comparing plenum pressure with average draft, you can see that the two are in phase. In addition, the pressures into the bow and stern seals are in phase with the plenum pressure.

Figures 16, 17, and 18 show the stern seal leakage that occurs under different wave lengths. The value of stern seal leakage is based upon a calm water baseline leakage rate of 6417 cubic feet per second at a plenum pressure of 92.8 pounds per square foot. Since it is not known precisely where all the leakage does occur in the craft, it is assumed that all of the baseline leakage does occur out the stern seal. The values of stern seal leakage, under wave conditions, are based upon the principle of Venturi flow. For the same area of stern seal gap, the amount of stern seal leakage will vary proportionally with the plenum pressure. As a result, the stern seal leakage rate is in phase with the plenum pressure. No bow or sidewall leakage occurred at the wave lengths shown.

The input fan flow rates to the bow seal, stern seal, and plenum are shown in Figs. 19, 20, and 21. The fan flow rates are based on a function of pressure. Since the fan characteristics are nonlinear, a series of linear curve-fits for the pressure versus input fan flow rate is used. The slope of the pressure versus input fan flow rate

changes at different locations on the plot, with the result that the fan flow rate causes a more rapid increase in fan flow rates at lower pressures. Basically the fan flow inputs are out of phase with the pressures. In Fig. 19 and 21, negative fan flow inputs to the bow seal are not shown. The maximum negative value that did occur was approximately -150 pounds per square foot.

Figures 22, 23, and 24 show the total fan power required to produce the necessary input of air flow. Of interest here is to note the double frequency of oscillation that occurs. The total fan power is based upon a summation of fan power required for the bow seal, plenum, and stern seal. In turn each individual fan power is based upon the pressure times the fan flow input. Since pressures and fan flow inputs are out of phase, the maximum power requirements will occur when the pressures are the largest and also when the fan flow inputs are the largest. This results in the double frequency of oscillation of the total fan power requirement.

2. Astern Waves

Wave lengths of 72 feet (λ) and 108 feet ($3/2\ \lambda$) are shown in Figs. 25 through 40. Wave lengths of 36 feet are not shown for astern waves since they follow approximately the same sinusoidal phase relation established for the 36 foot wavelength of ahead waves.

Figures 25 and 26 show the relationship of the center of gravity acceleration to the wave. The maximum

acceleration lags the wave by a small amount. Figures 27 and 28 show that the bow acceleration is in phase with the center of gravity acceleration, as is to be expected for a rigid type ship.

The average draft response is shown in Fig. 29 and 30. No phase comparison between draft and wave can be made since this is an average value. The value of draft is primarily dependent on the value of plenum pressure.

Figures 31 and 32 show the response of plenum pressure to different wave lengths. Basically the plenum pressure follows the average draft response, but Fig. 32 shows how the plenum pressure can deviate from a sinusoidal motion. Both bow seal and stern seal pressures are in phase with the plenum pressure.

Figures 33 and 34 show the stern seal leakage for different wave lengths. The stern seal leakage rates are in phase with the plenum pressure response as a result of the same reasoning used for ahead waves.

Figures 35 and 36 show the bow and sidewall leakage rates. No sidewall leakage occurs at the 108 foot wave length (Fig. 36). Leakage will only occur when a gap is created between the bow seal and water surface and/or the sidewall and water surface. The amount of leakage rate is dependent upon the area of the gap created and the pressure of the plenum. The principle of Venturi flow applies to the leakage rate. When sidewall leakage did occur (Fig. 35), this leakage occurred at the forward part of the sidewall.

The input fan flow rates are shown in Figs. 37 and 38. As with ahead waves, the input fan flow rates are out of phase with the pressures.

Figures 39 and 40 show the total fan power required. Again notice the double frequency of oscillation that occurs. This occurs because of the same reasoning used for explaining the ahead wave case.

E. AVERAGE AND FLUCTUATION VALUES OF VARIABLES

Average and fluctuation values of selected variables for various speeds, wave directions, wave lengths, and wave amplitudes are shown in Figs. 41 through 80. The variables that are shown in the different figures are: Pitch, Center of Gravity Acceleration, Bow Acceleration, Draft, Bow and Stern Seal Pressures, Plenum Pressures, Stern Seal Leakage Rate, Bow Seal Input Fan Flow Rate, Plenum Input Fan Flow Rate, Stern Seal Input Fan Flow Rate, and Total Fan Power. The fluctuations, and not the average values, of Bow Acceleration and Center of Gravity Acceleration are shown since their average values are approximately zero.

The average values were calculated by adding the values of a number of data points (20 to 50) along a full wave encounter cycle and dividing by the number of data points. Either one or more full wave cycles were used depending on the number of data points available in each wave cycle. This summation of values was necessary because of the non-sinusoidal nature of certain variables.

The values of fluctuations used were based on taking the difference between the maximum and minimum values of the variables.

The dots shown in Figs. 41 through 80 represent the data points. No interpolation was used between the data points.

The values of wave length and wave amplitude are denoted on the figures at the right hand side of the last data point used. A 36 foot wave length and 1 foot wave amplitude is denoted as 36 x 1.

Figures 41 through 60 are for ahead waves (directly on the bow) and Figs. 61 through 80 are for astern waves (directly astern).

A discussion of the results obtained in Figs. 41 through 80 is contained in later sections.

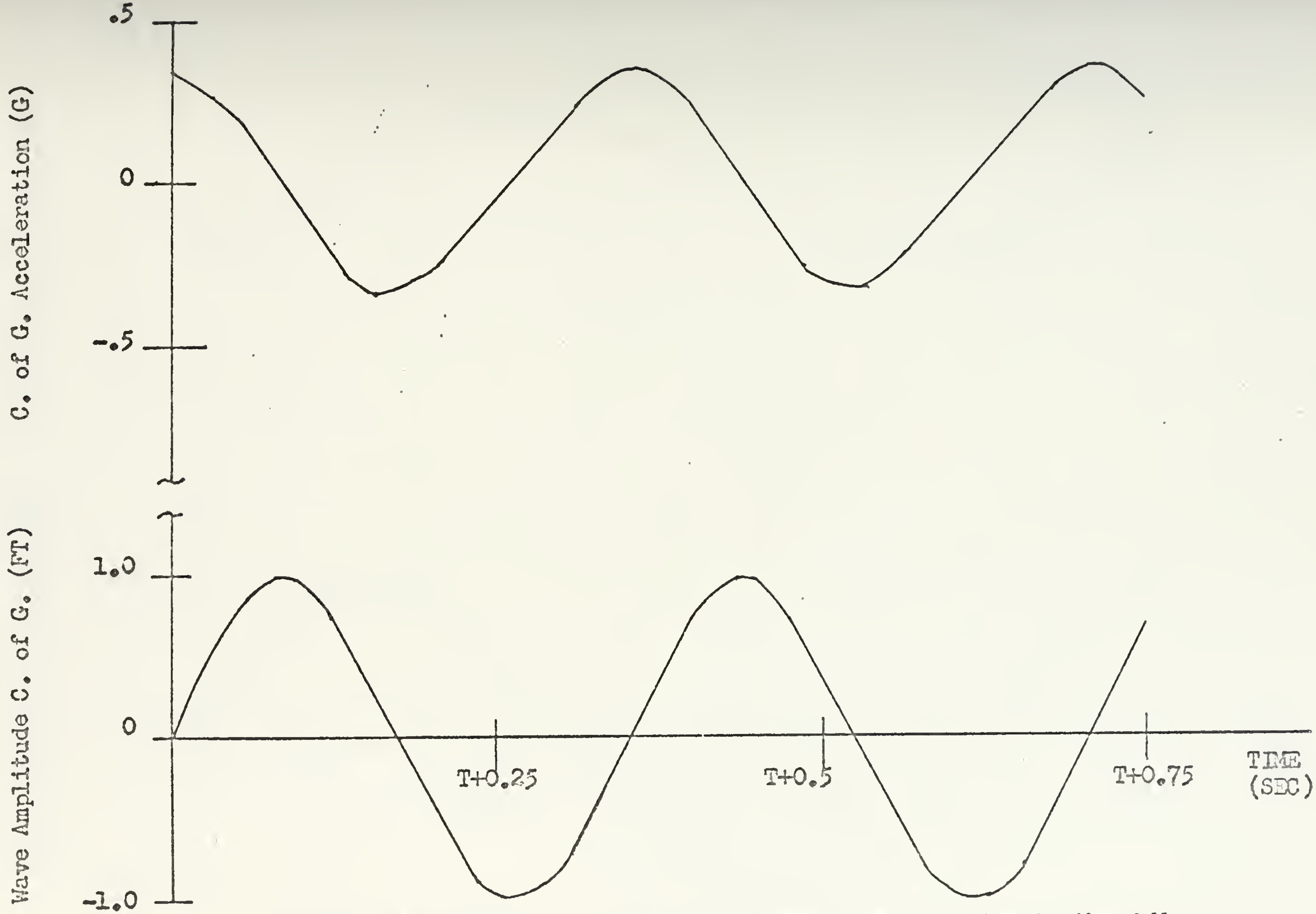


Figure 4. Response of Center of Gravity Acceleration to Ahead Wave

Initial Conditions: Speed 60 Knots, Wave Length 36 Feet, Wave Amplitude 1 Foot

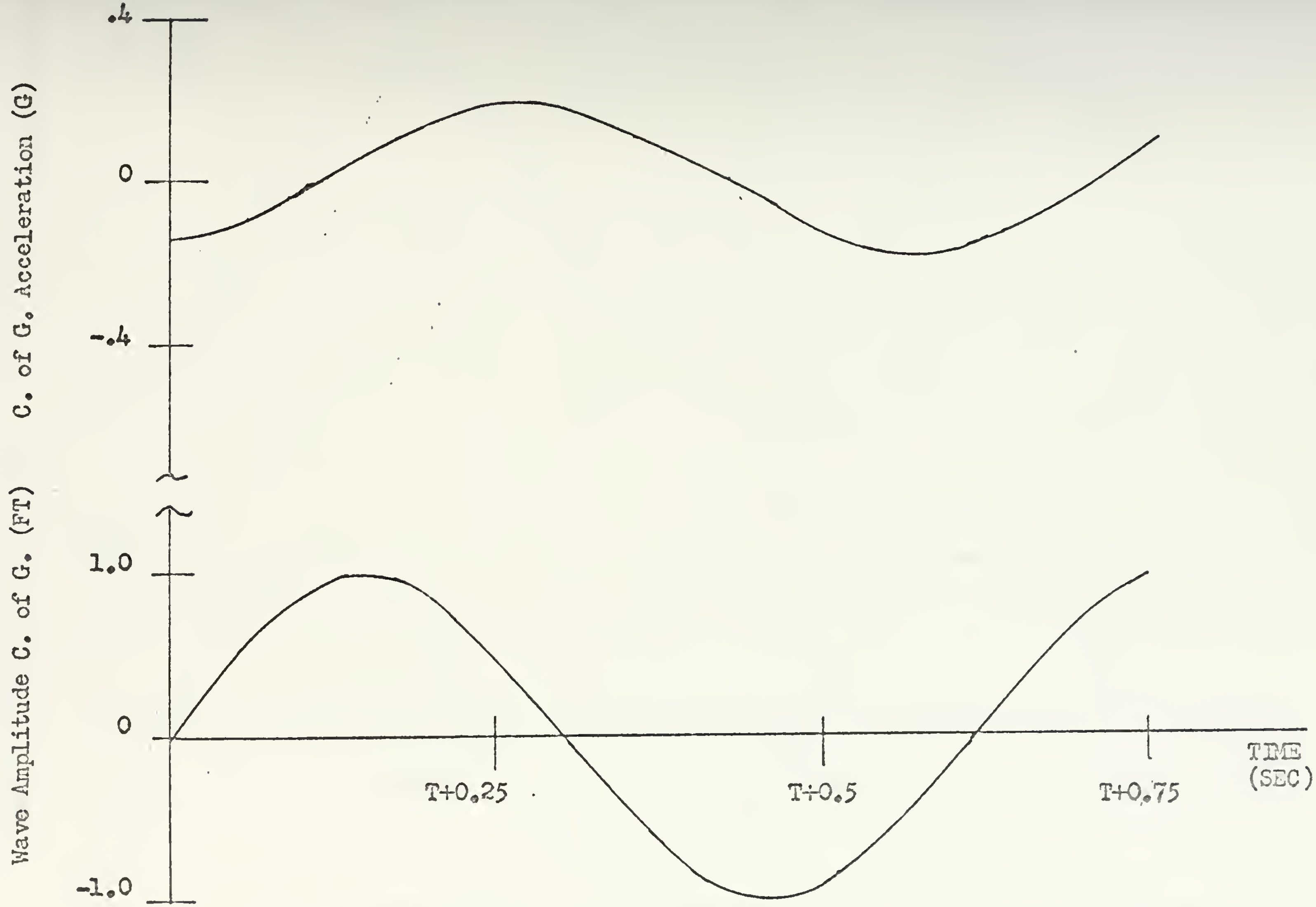


Figure 5. Response of Center of Gravity Acceleration to Ahead Wave

Initial Conditions: Speed 60 Knots, Wave Length 72 Feet, Wave Amplitude 1 Foot

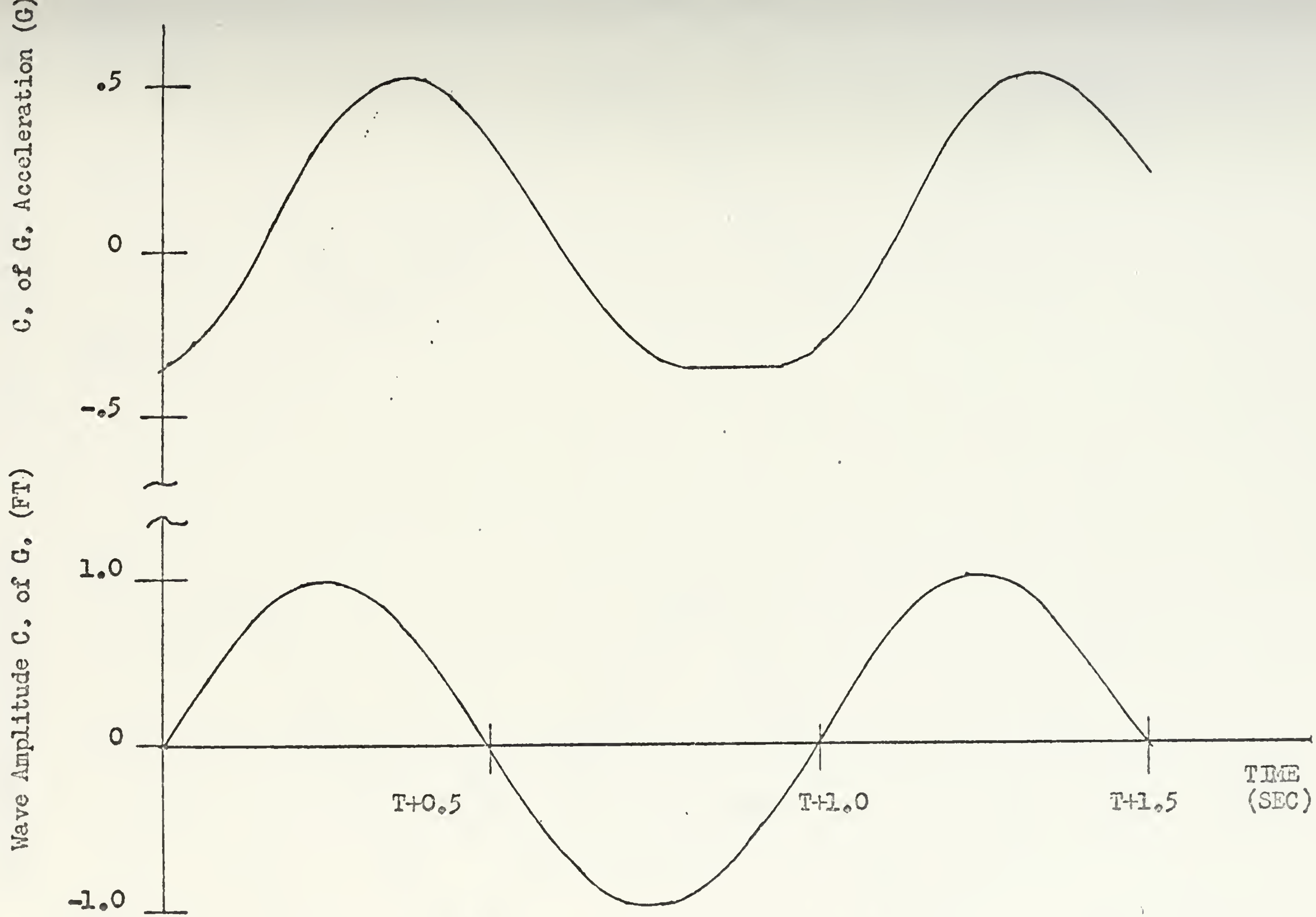


Figure 6. Response of Center of Gravity Acceleration to Ahead Wave

Initial Conditions: Speed 60 Knots, Wave Length 103 Feet, Wave Amplitude 1 Foot

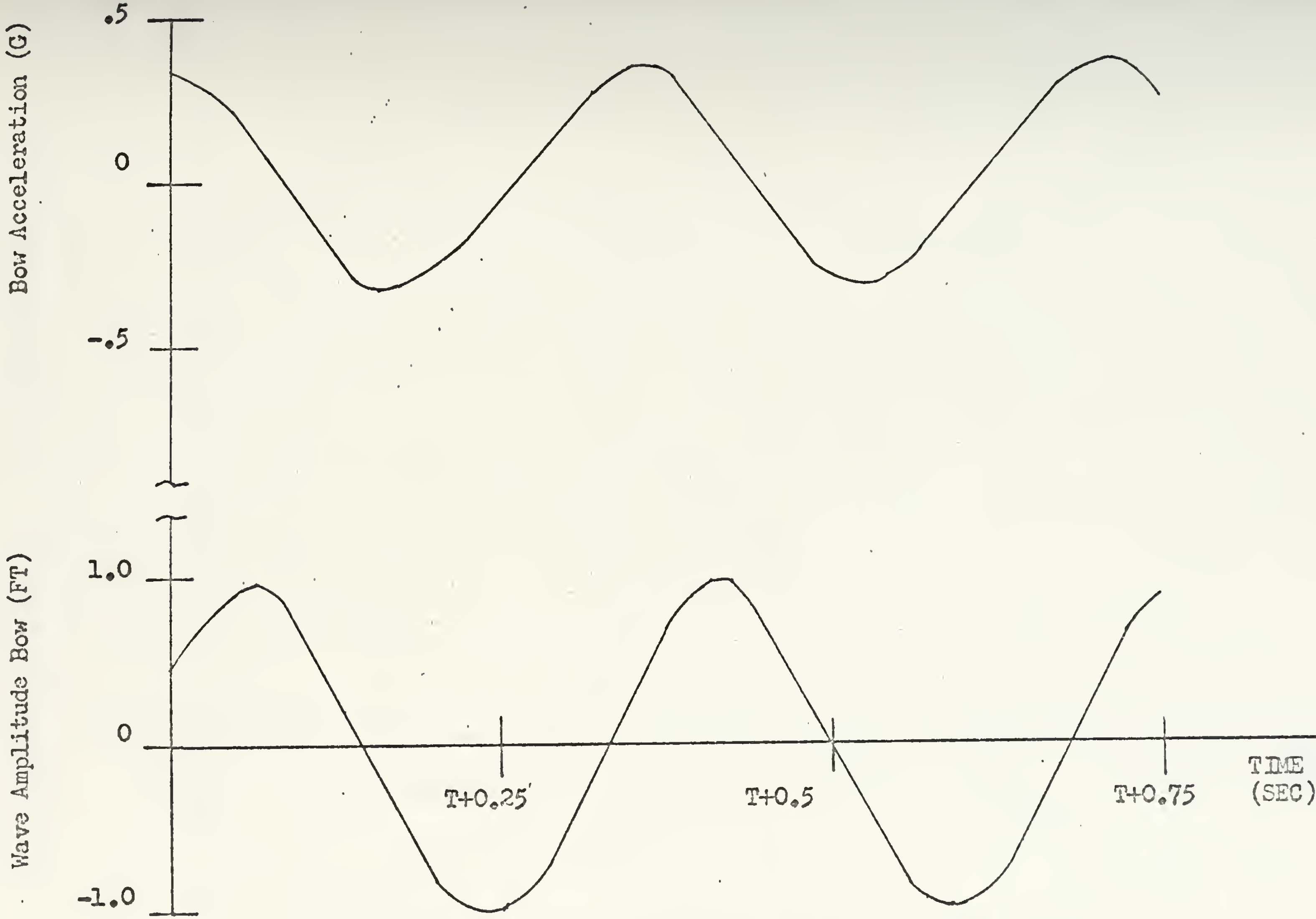


Figure 7. Response of Bow Acceleration to Ahead Wave

Initial Conditions: Speed 60 Knots, Wave Length 36 Feet, Wave Amplitude 1 Foot

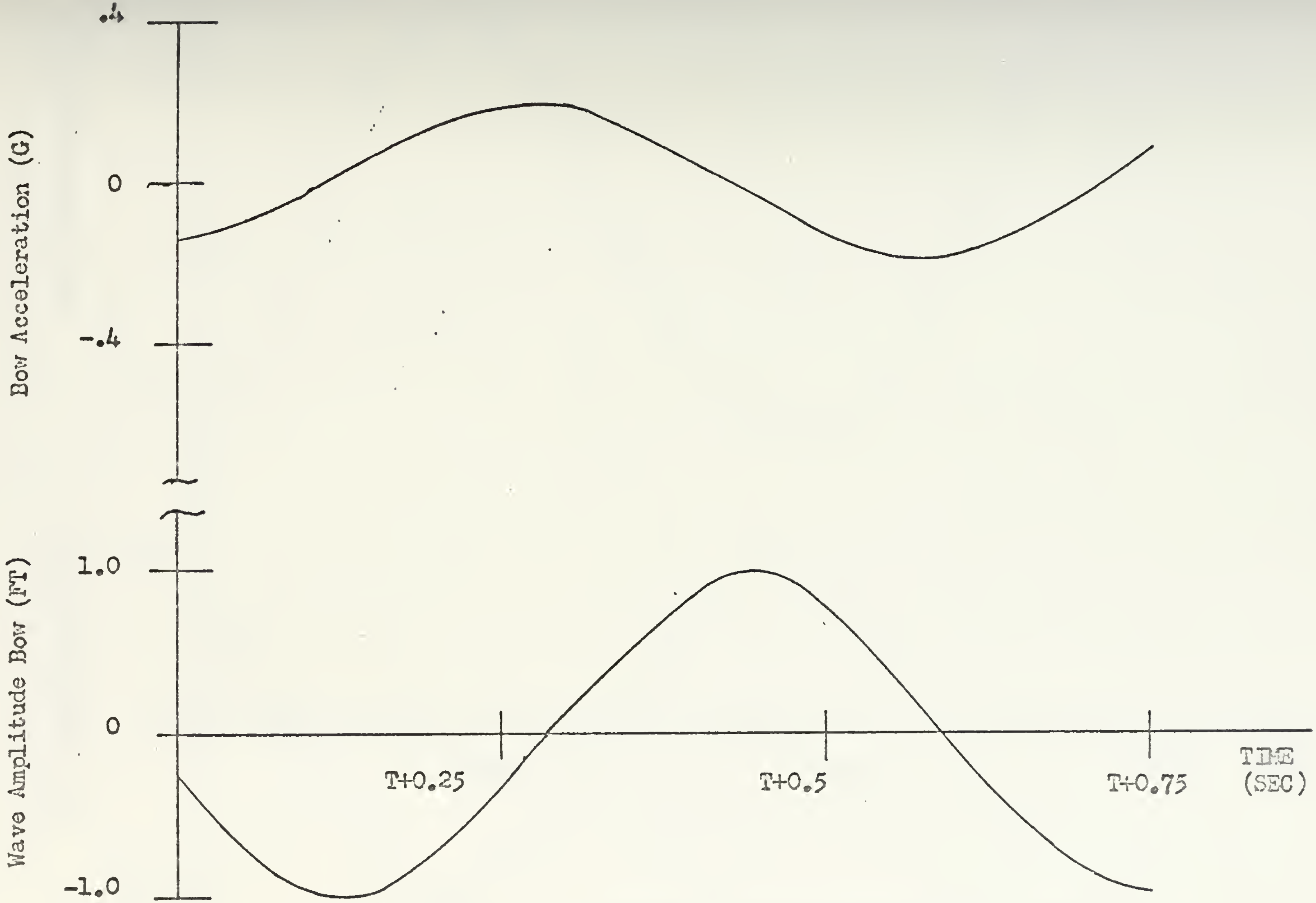


Figure 8. Response of Bow Acceleration to Ahead Wave

Initial Conditions: Speed 60 Knots, Wave Length 72 Feet, Wave Amplitude 1 Foot

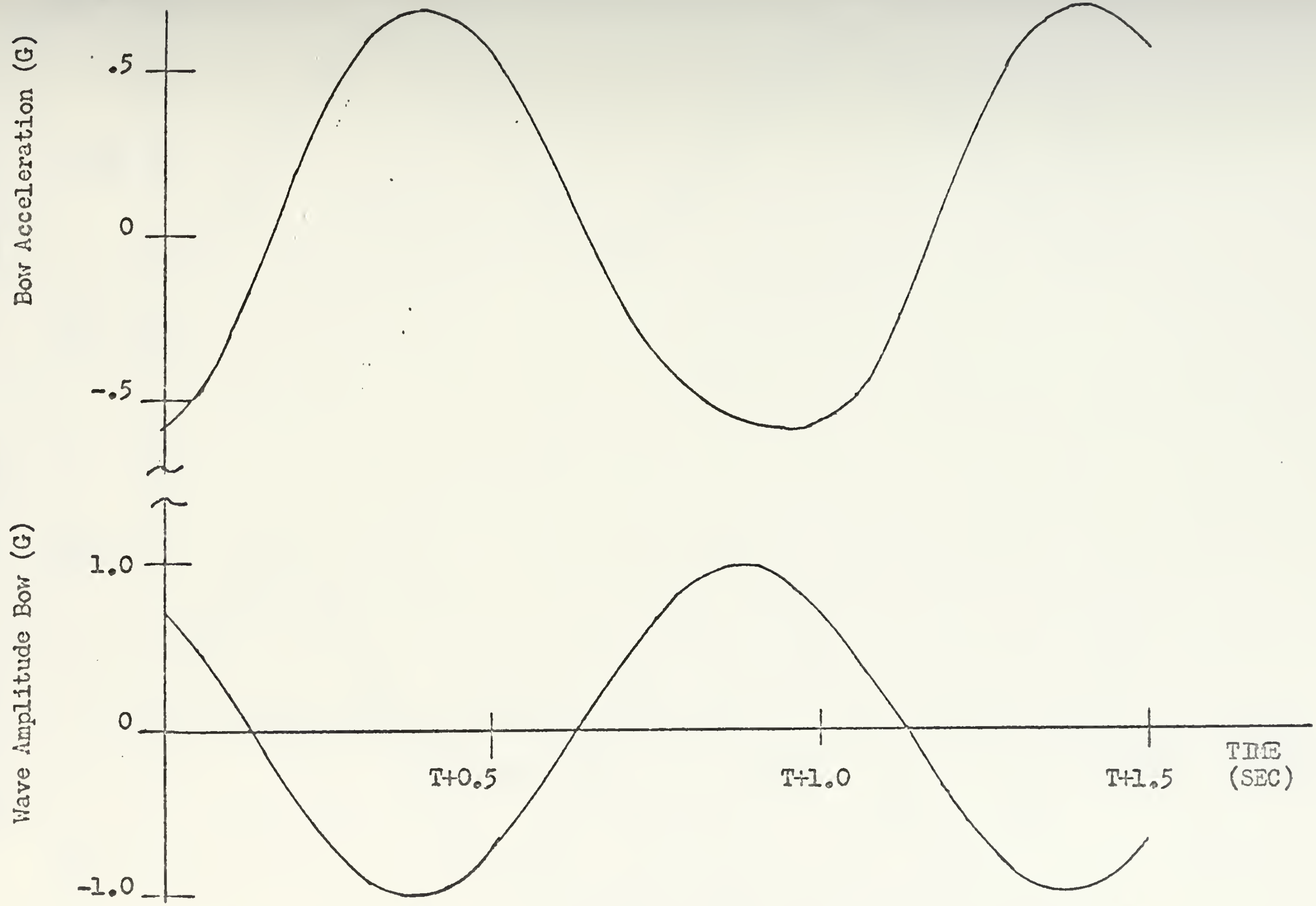


Figure 9. Response of Bow Acceleration to Ahead Wave

Initial Conditions: Speed 60 Knots, Wave Length 108 Feet, Wave Amplitude 1 Foot

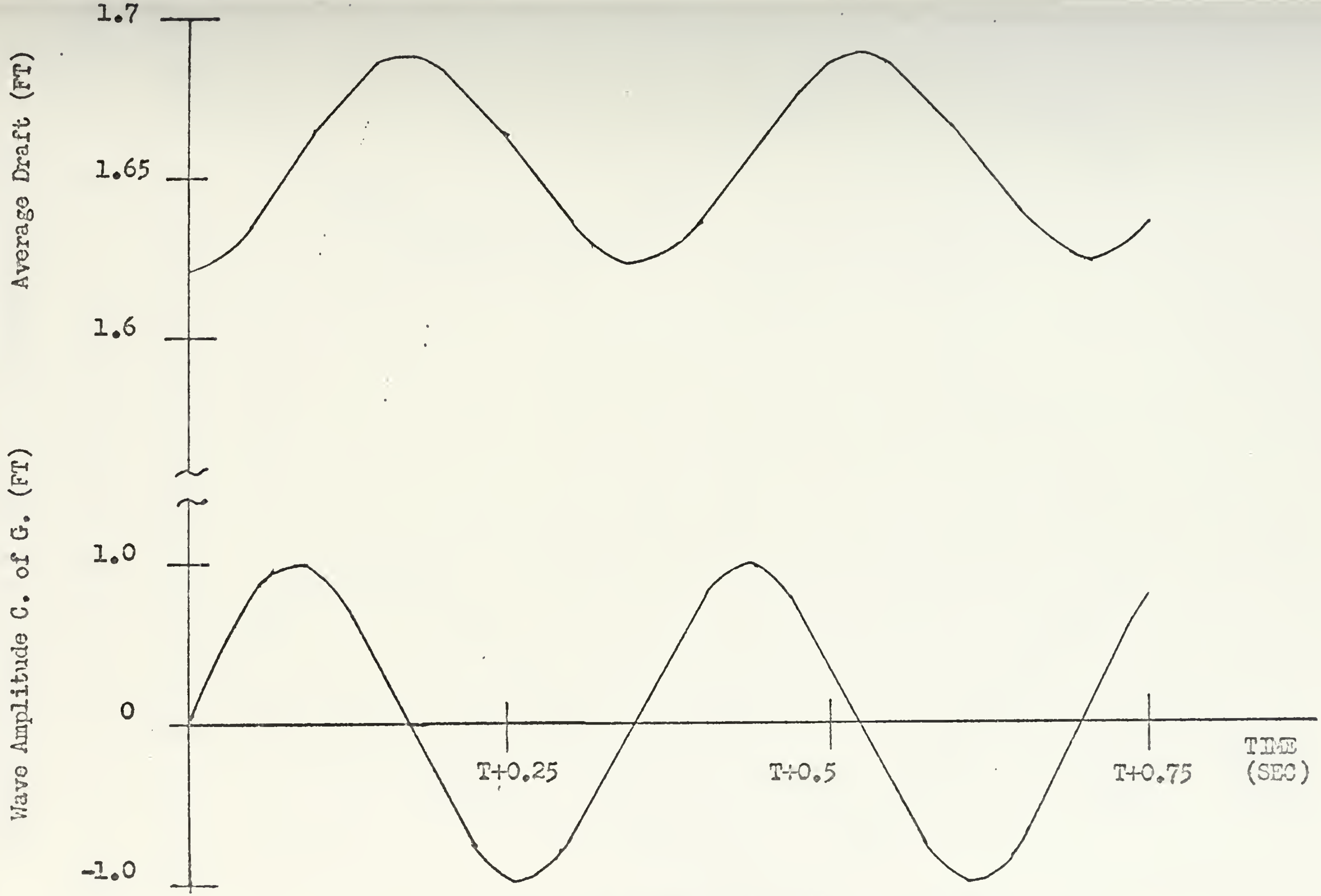


Figure 10. Draft Response to Ahead Wave

Initial Conditions: Speed 60 Knots, Wave Length 36 Feet, Wave Amplitude 1 Foot, Draft 1.033 Feet

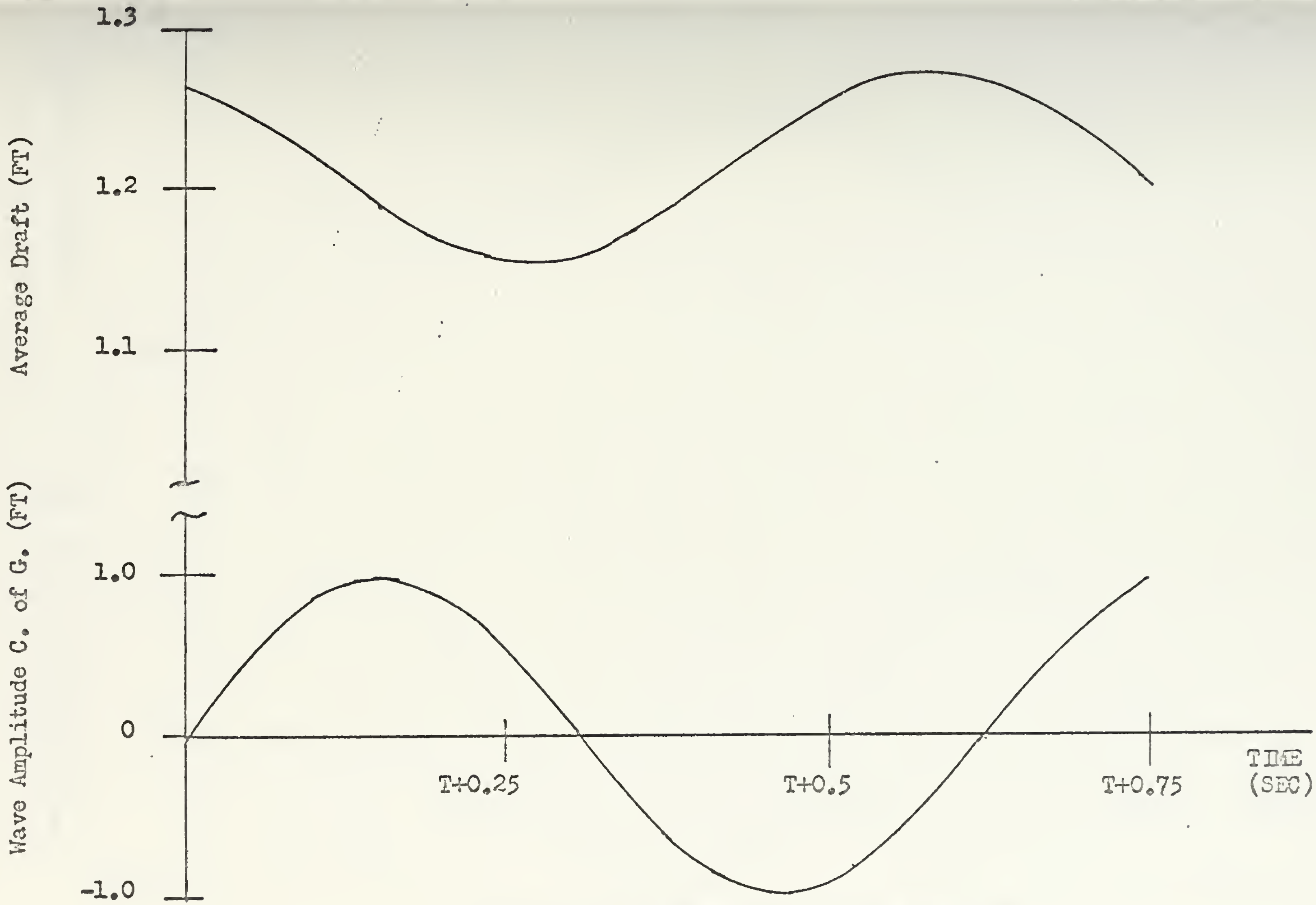


Figure 11. Draft Response to Ahead Wave

Initial Conditions: Speed 60 Knots, Wave Length 72 Feet, Wave Amplitude 1 Foot, Draft 1.033 Feet

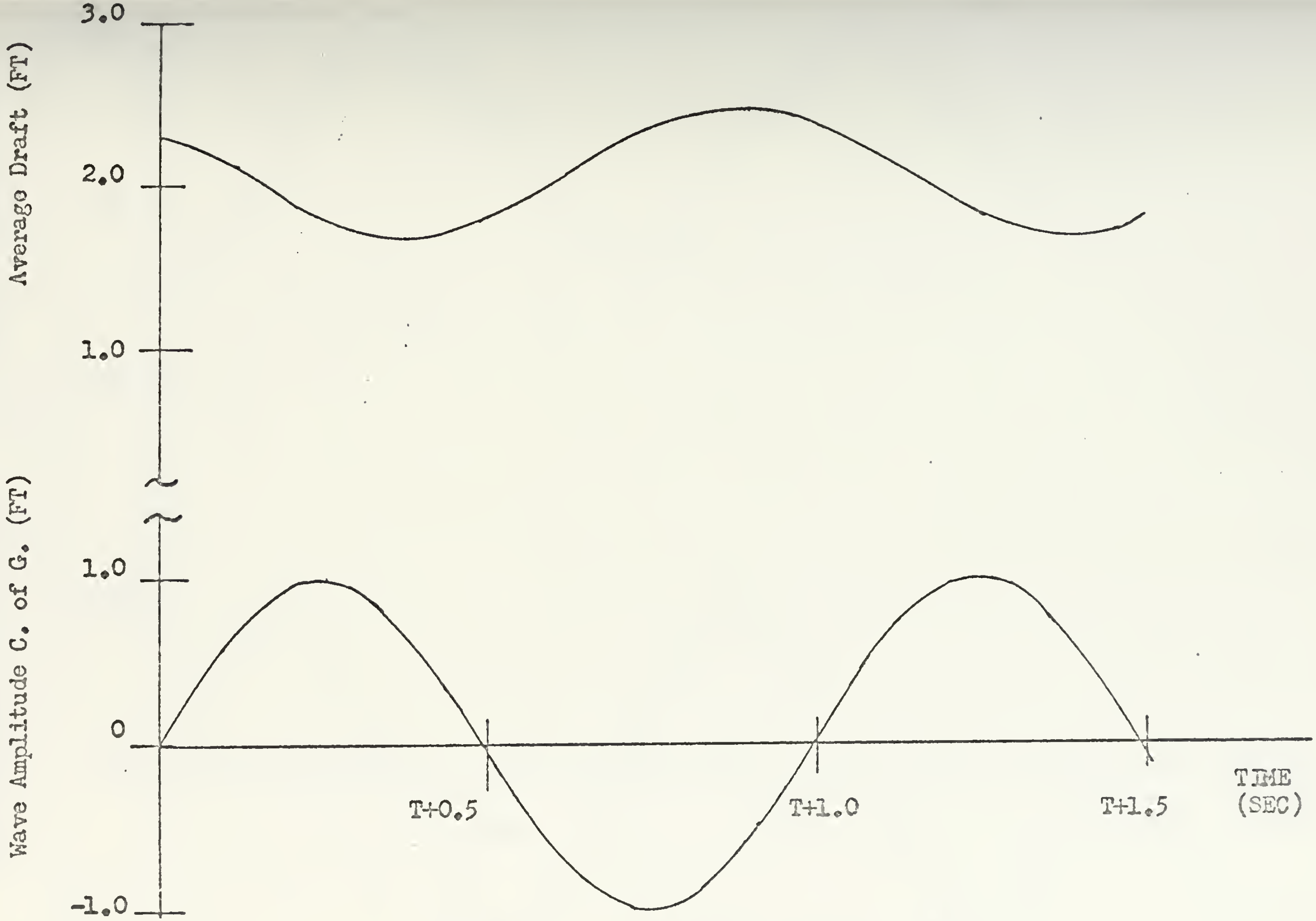


Figure 12. Draft Response to Ahead Wave

Initial Conditions: Speed 60 Knots, Wave Length 108 Feet, Wave Amplitude 1 Foot, Draft 1.033 Feet

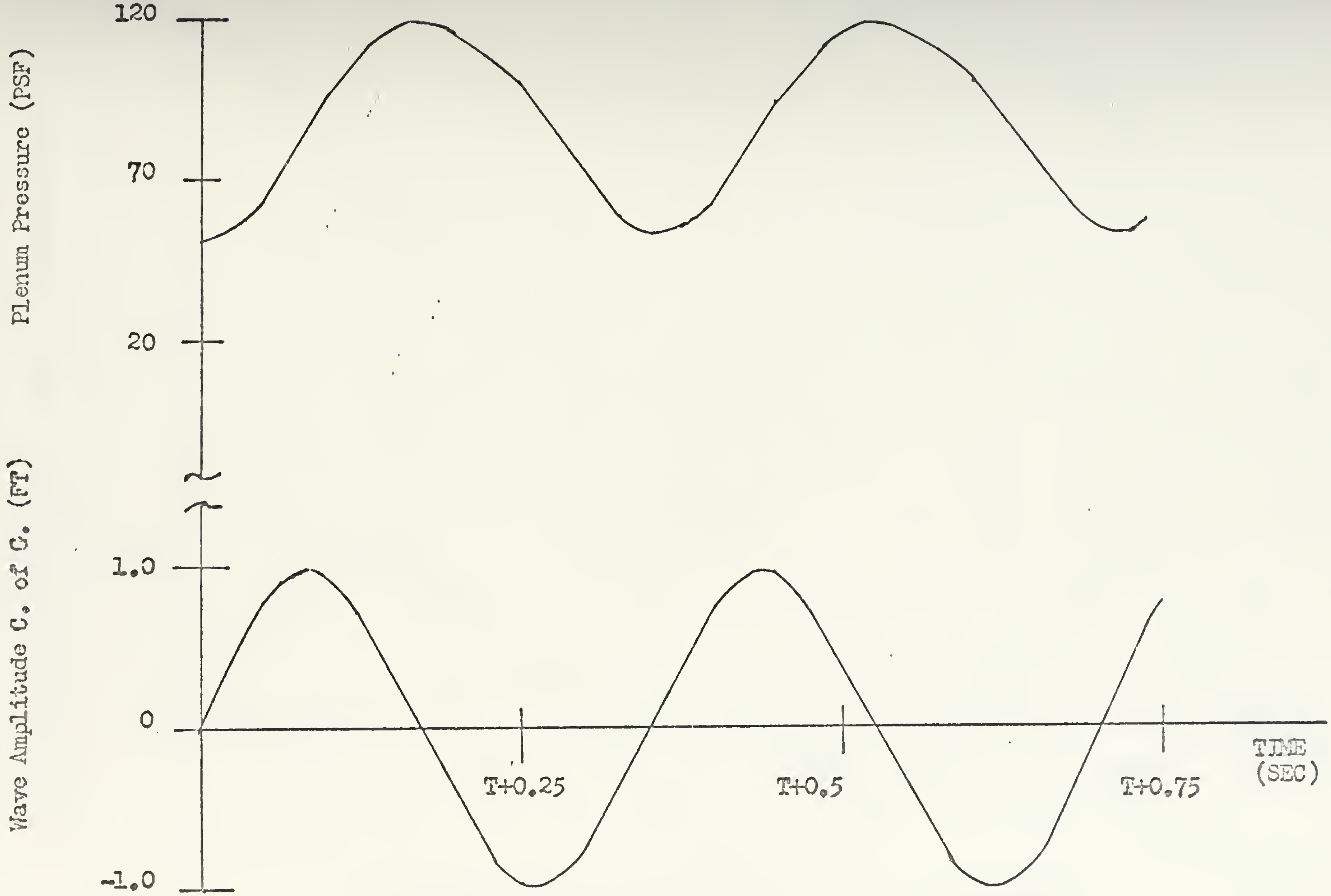


Figure 13. Response of Plenum Pressure to Ahead Wave

Initial Conditions: Speed 60 Knots, Wave Length 35 Feet, Wave Amplitude 1 Foot, Plenum Pressure 92.8 PSF

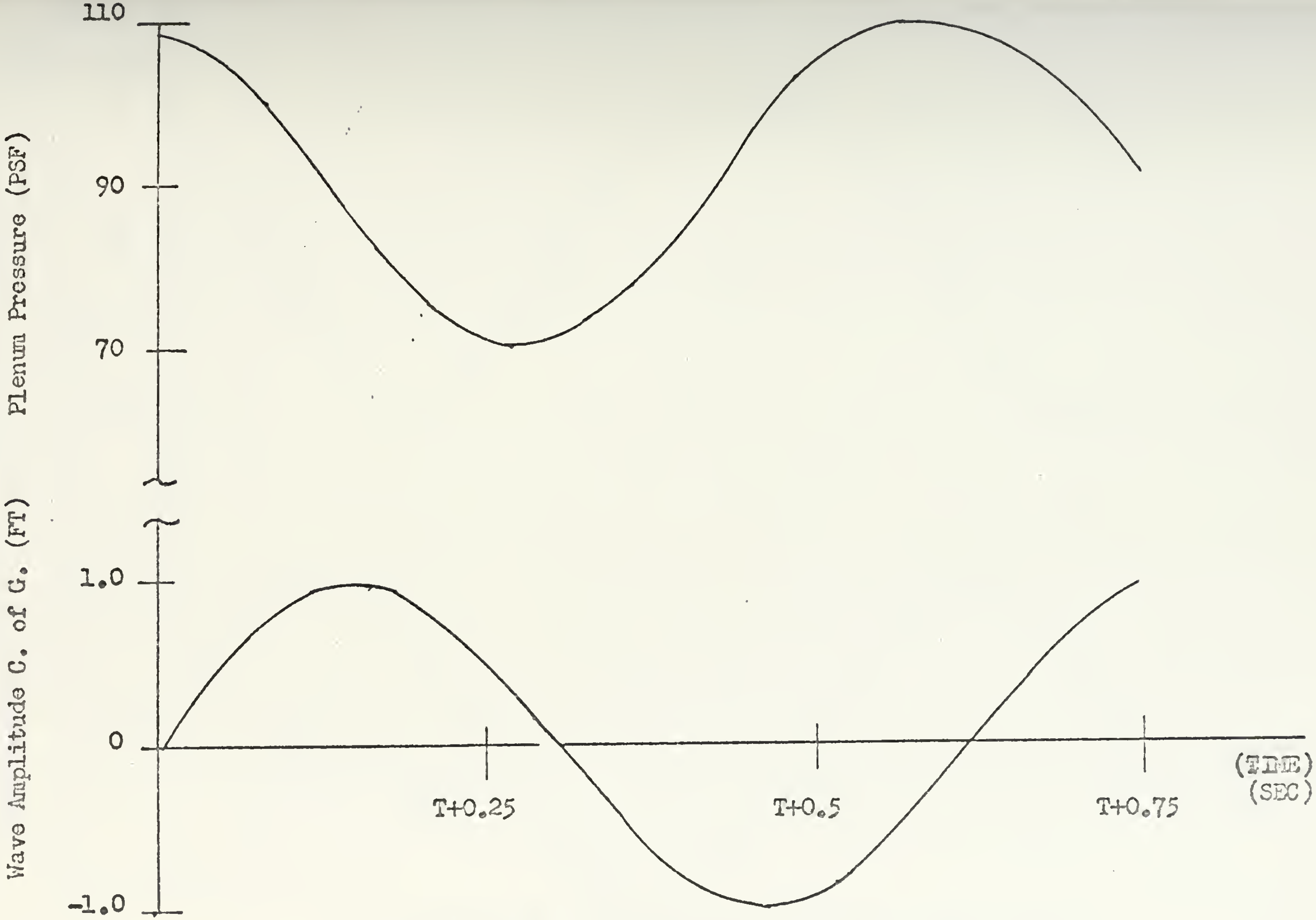


Figure 14. Response of Plenum Pressure to Ahead Wave

Initial Conditions: Speed 60 Knots, Wave Length 72 Feet, Wave Amplitude 1 Foot, Plenum Pressure 92.8 PSF

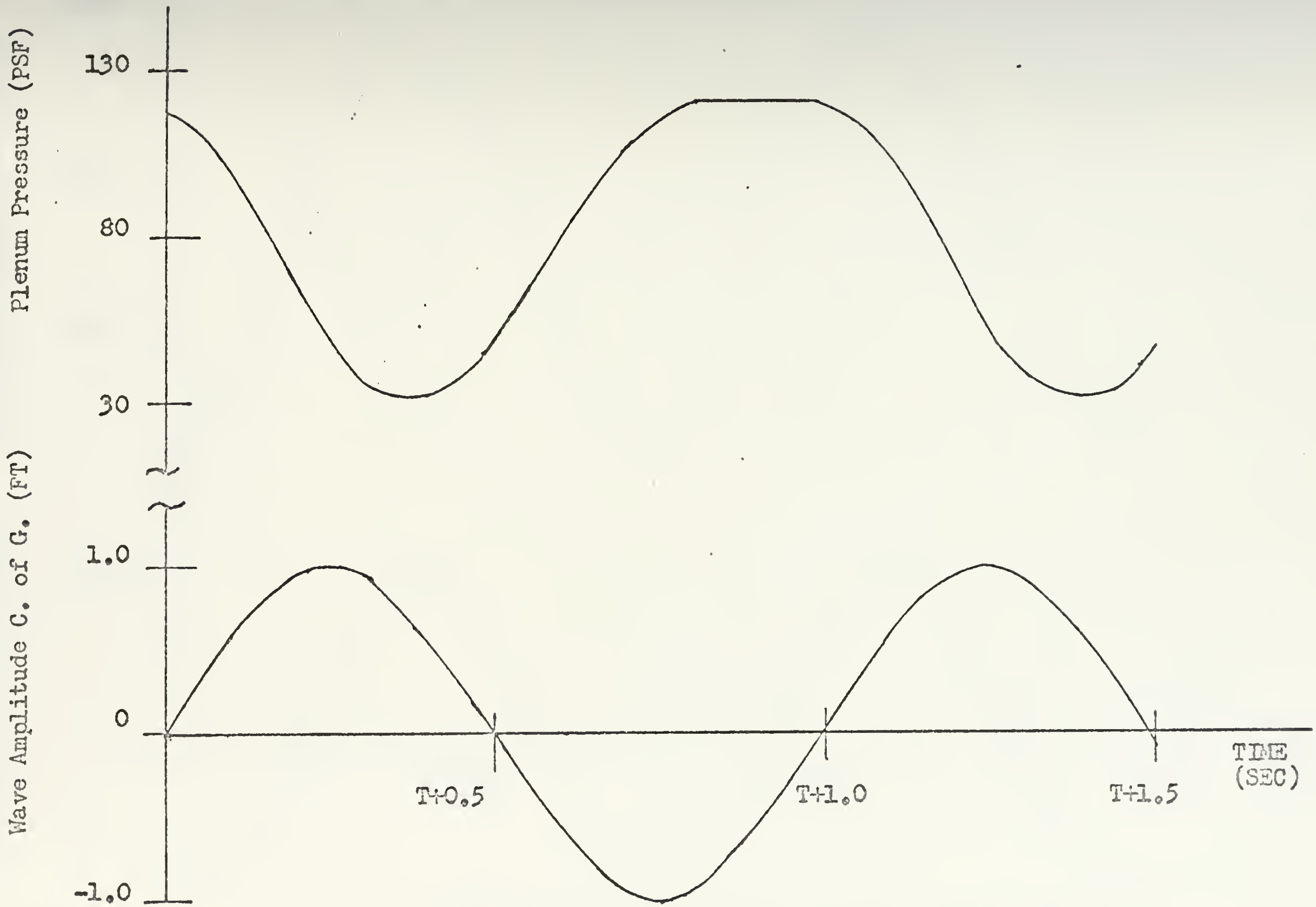


Figure 15. Response of Plenum Pressure to Ahead Wave

Initial Conditions: Speed 60 Knots, Wave Length 108 Feet, Wave Amplitude 1 Foot, Plenum Pressure 92.8 PSF

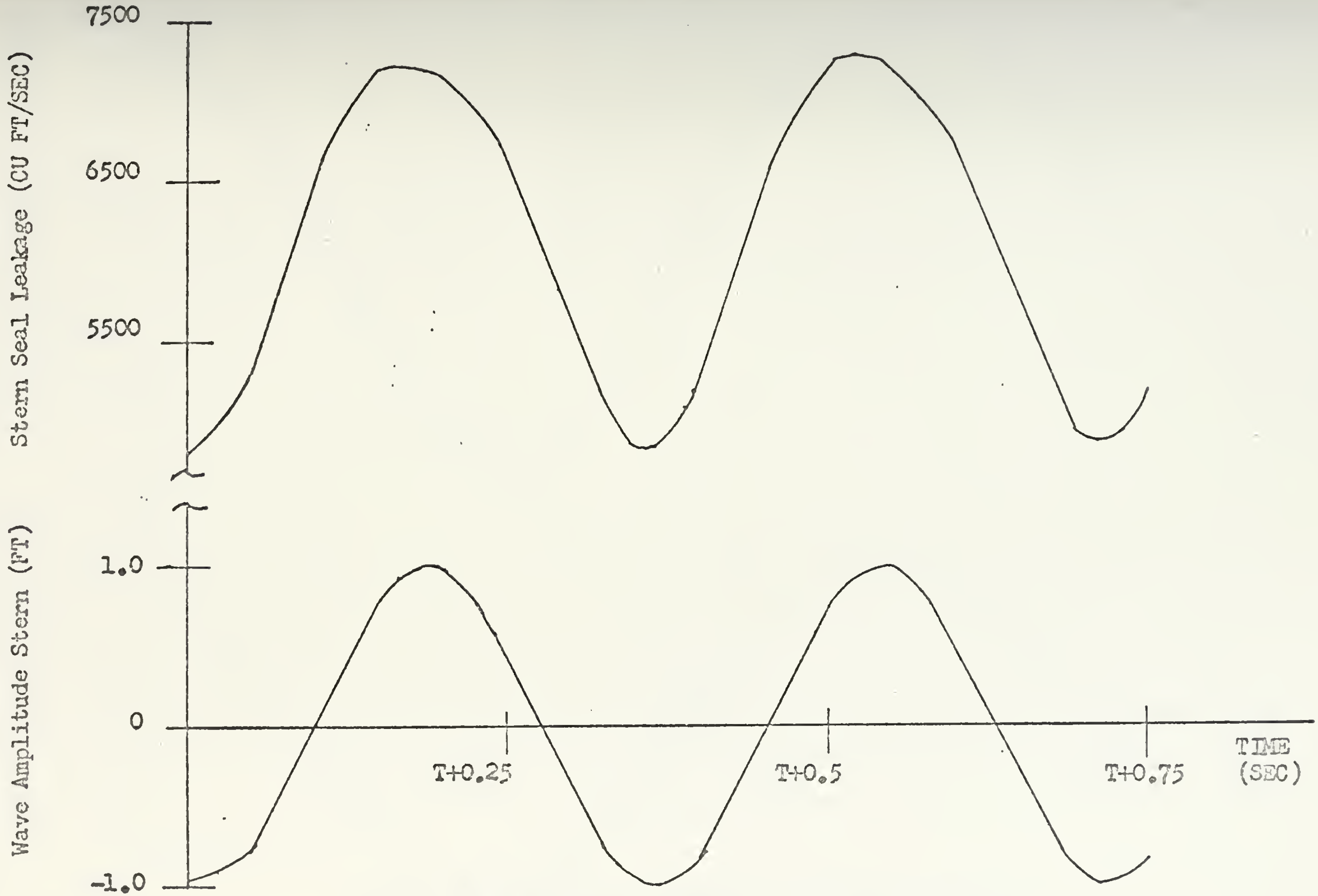


Figure 16. Stern Seal Leakage Rate for Ahead Wave

Initial Conditions: Speed 60 Knots, Wave Length 36 Feet, Wave Amplitude 1 Foot, Stern Seal Leakage Rate 6417 Cubic Feet/Second

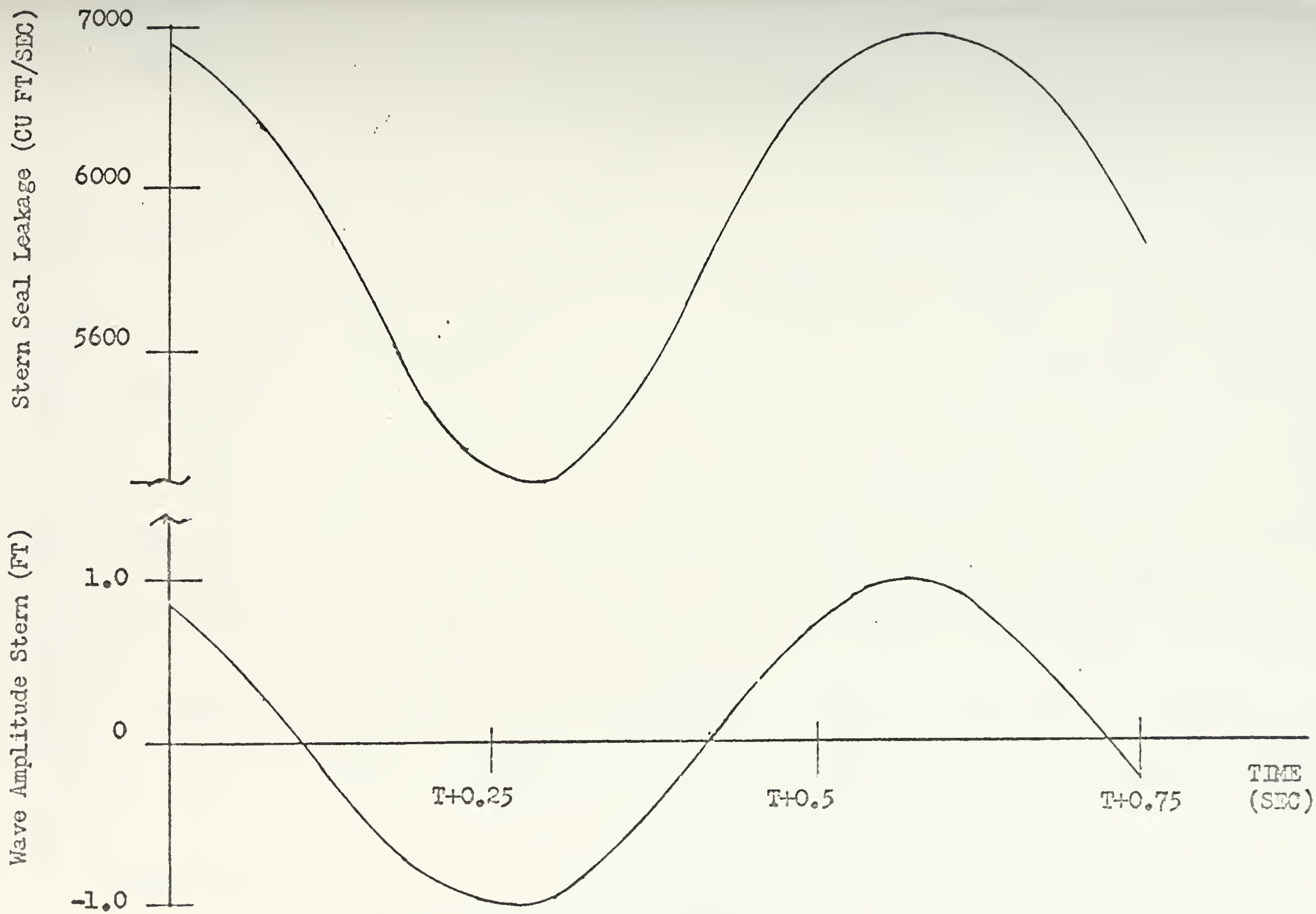


Figure 17. Stern Seal Leakage Rate for Ahead Wave

Initial Conditions: Speed 60 Knots, Wave Length 72 Feet, Wave Amplitude 1 Foot, Stern Seal Leakage Rate 6417 Cubic Feet/Second

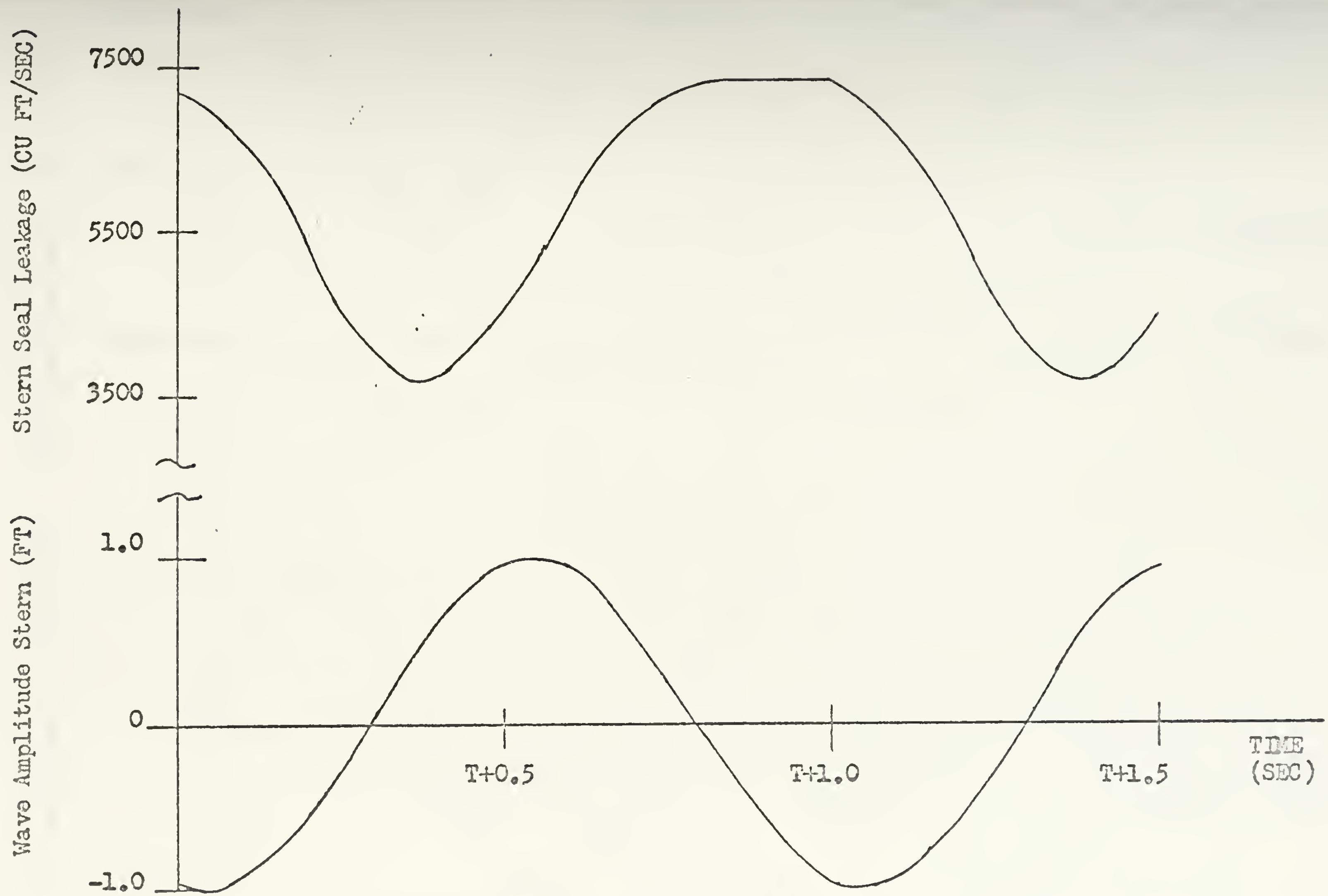


Figure 18. Stern Seal Leakage Rate for Ahead Wave

Initial Conditions: Speed 60 Knots, Wave Length 108 Feet, Wave Amplitude 1 Foot, Stern Seal Leakage Rate 6417 Cubic Feet/Second

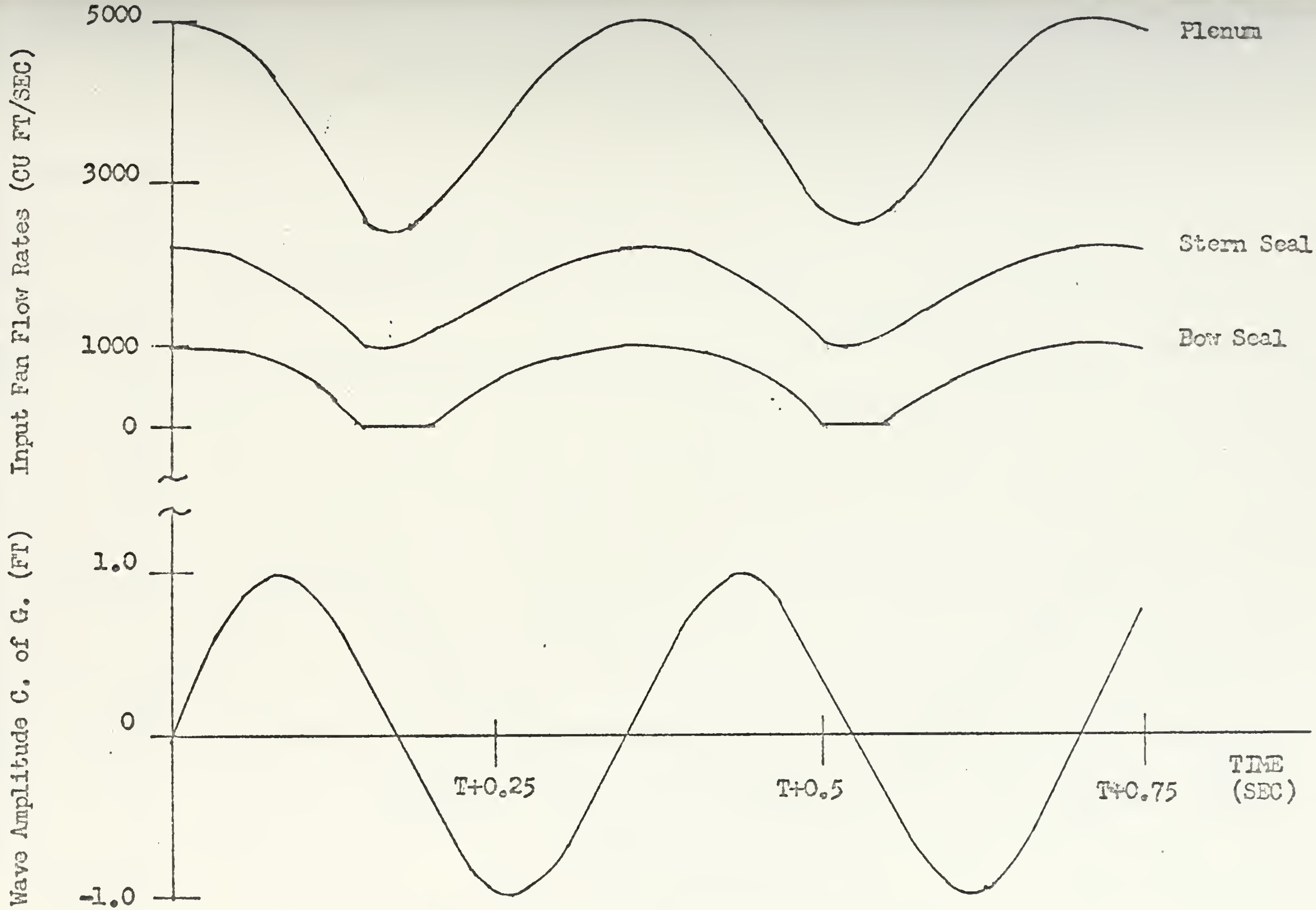


Figure 19. Input Fan Flow Rates for Ahead Wave

Initial Conditions: Speed 60 Knots, Wave Length 36 Feet, Wave Amplitude 1 Foot

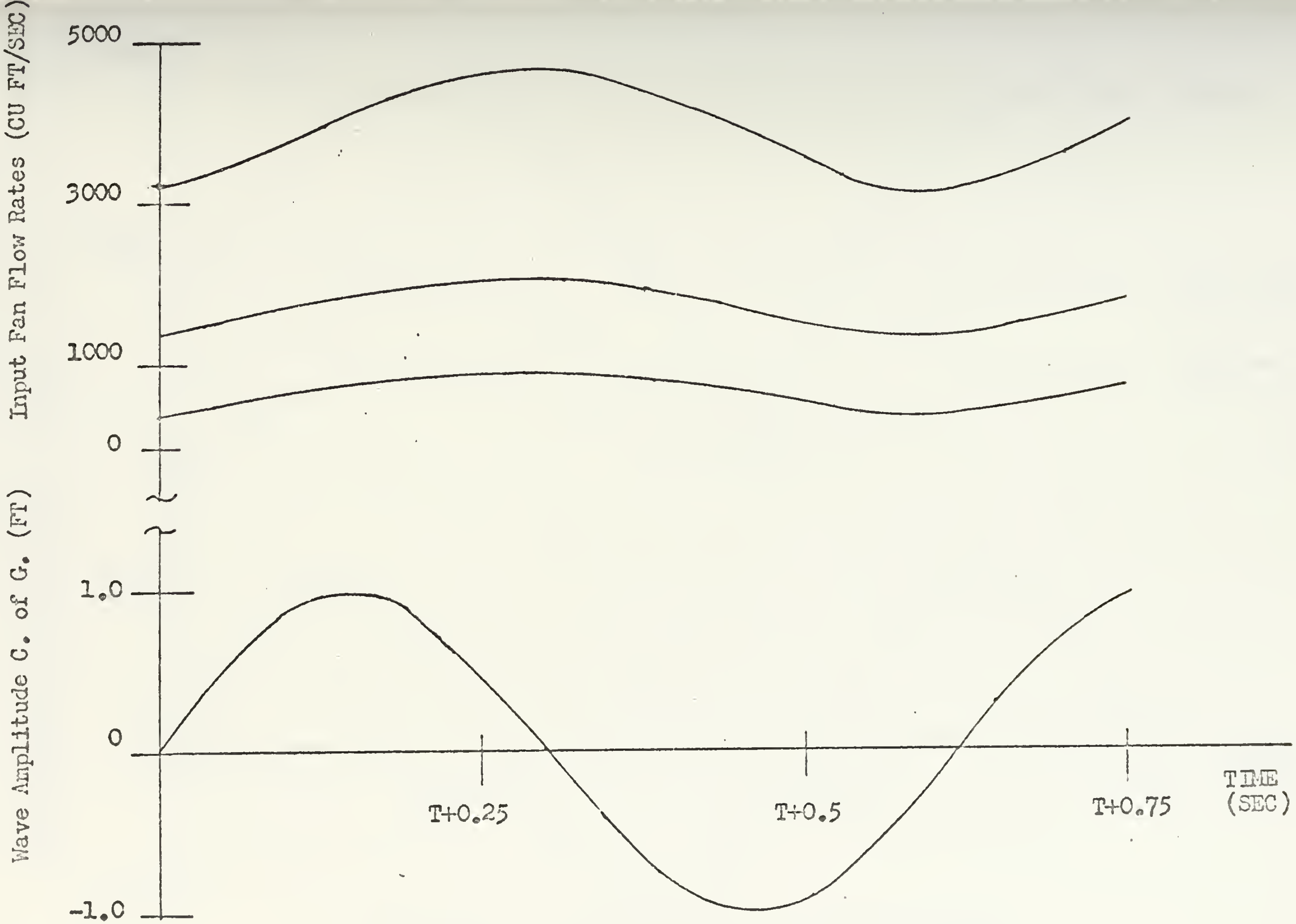


Figure 20. Input Fan Flow Rates for Ahead Wave

Initial Conditions: Speed 60 Knots, Wave Length 72 Feet, Wave Amplitude 1 Foot

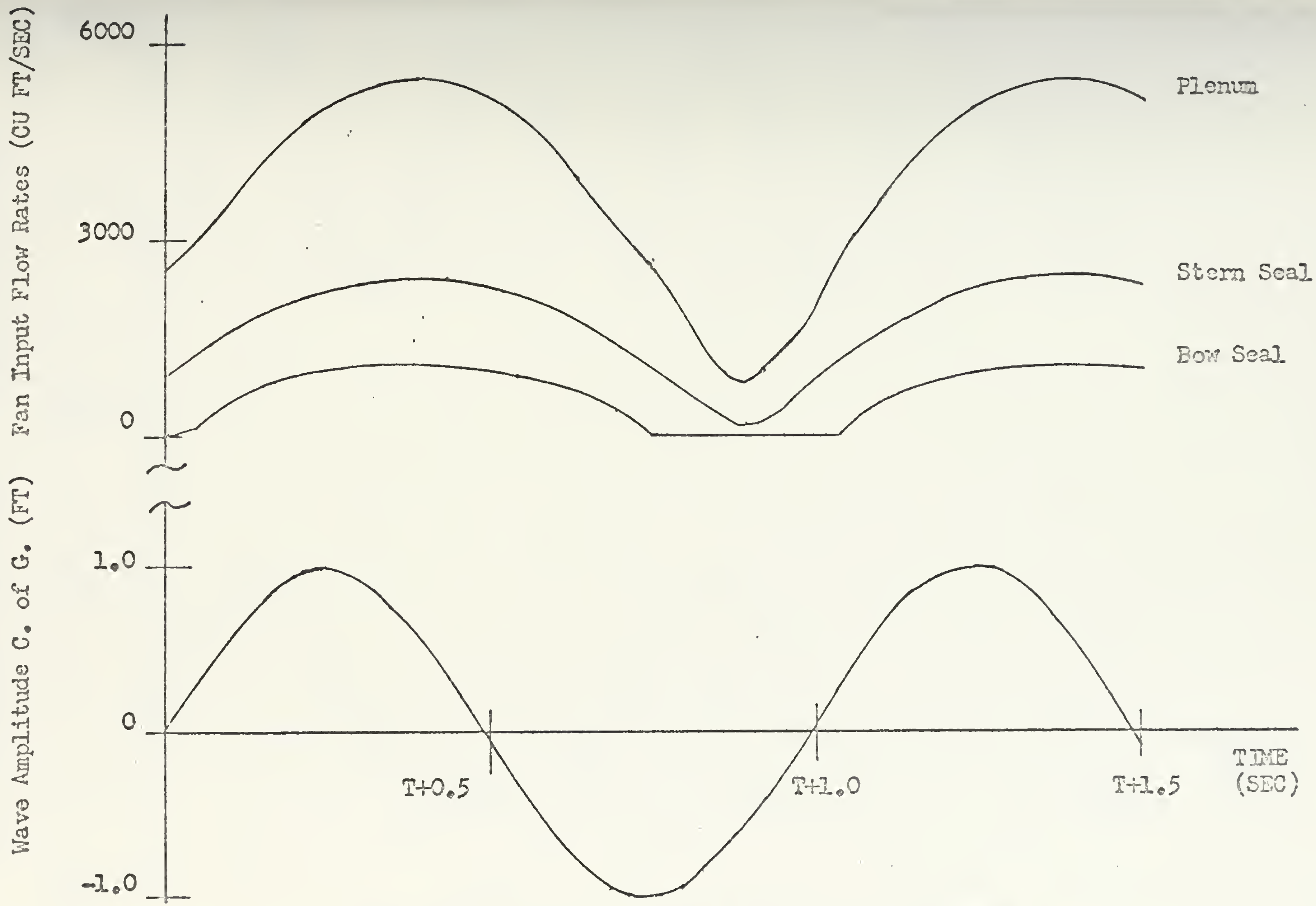


Figure 21. Input Fan Flow Rates for Ahead Wave

Initial Conditions: Speed 60 Knots, Wave Length 108 Feet, Wave Amplitude 1 Foot

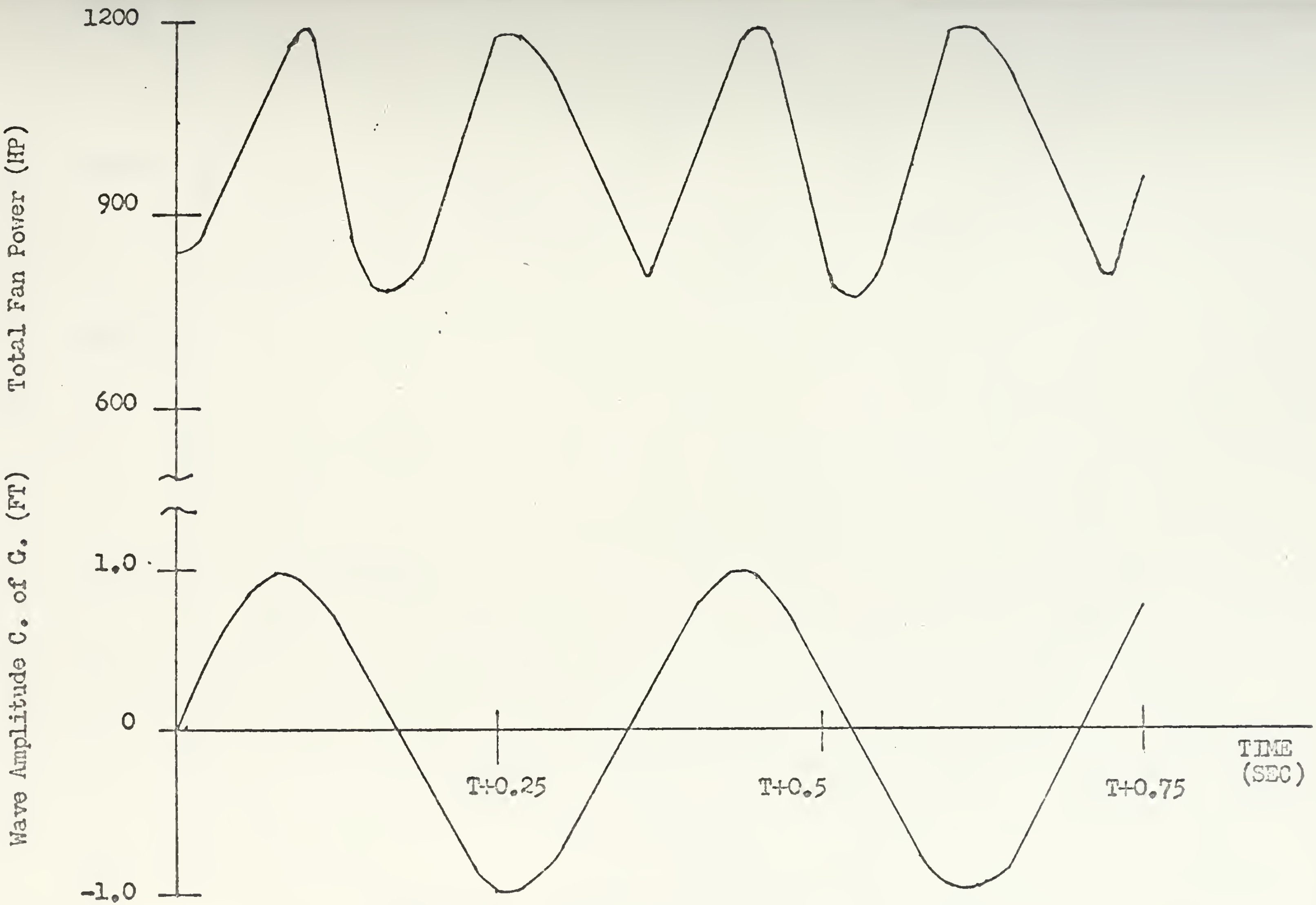


Figure 22. Total Fan Power Response to Ahead Wave

Initial Conditions: Speed 60 Knots, Wave Length 36 Feet, Wave Amplitude 1 Foot

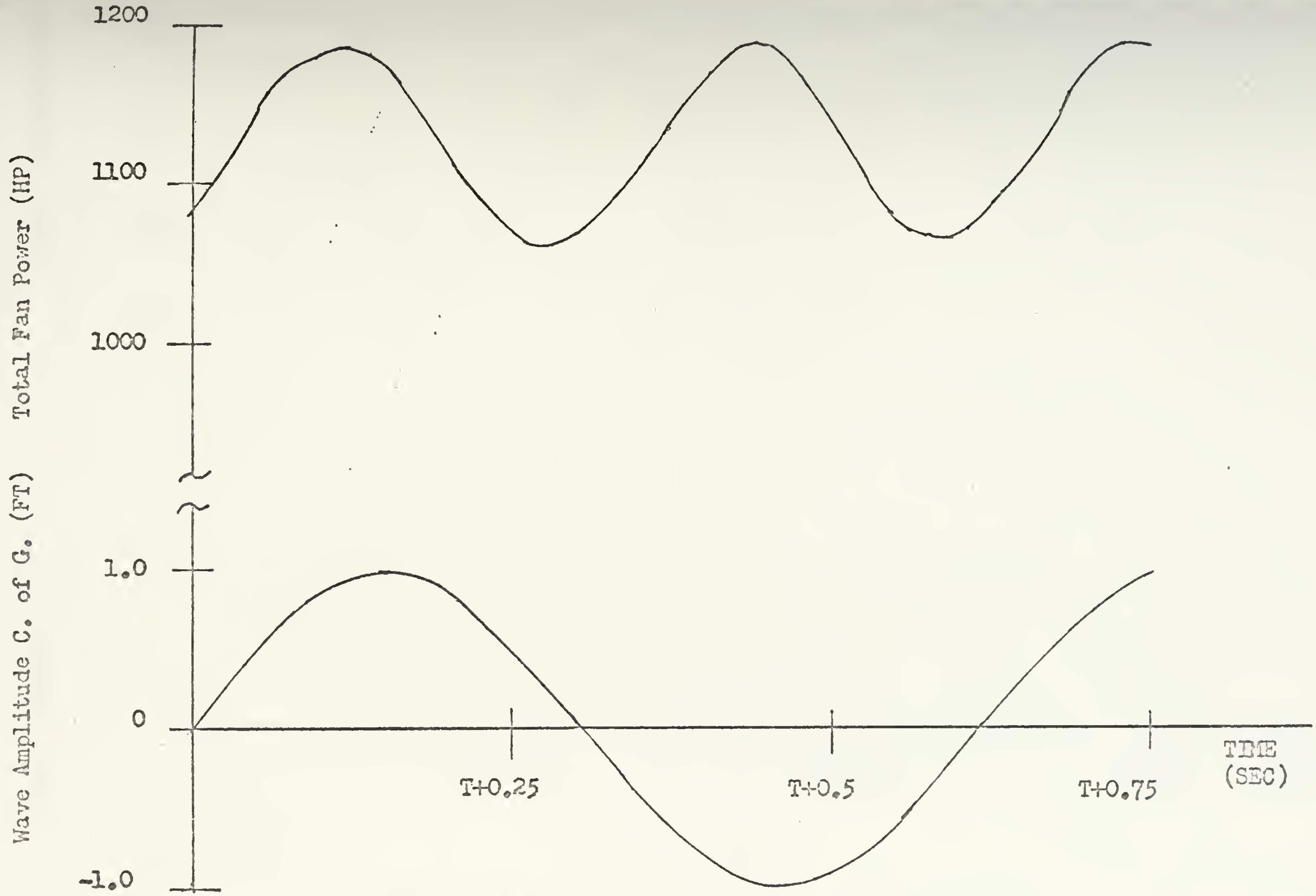


Figure 23. Total Fan Power Response to Ahead Wave

Initial Conditions: Speed 60 Knots, Wave Length 72 Feet, Wave Amplitude 1 Foot

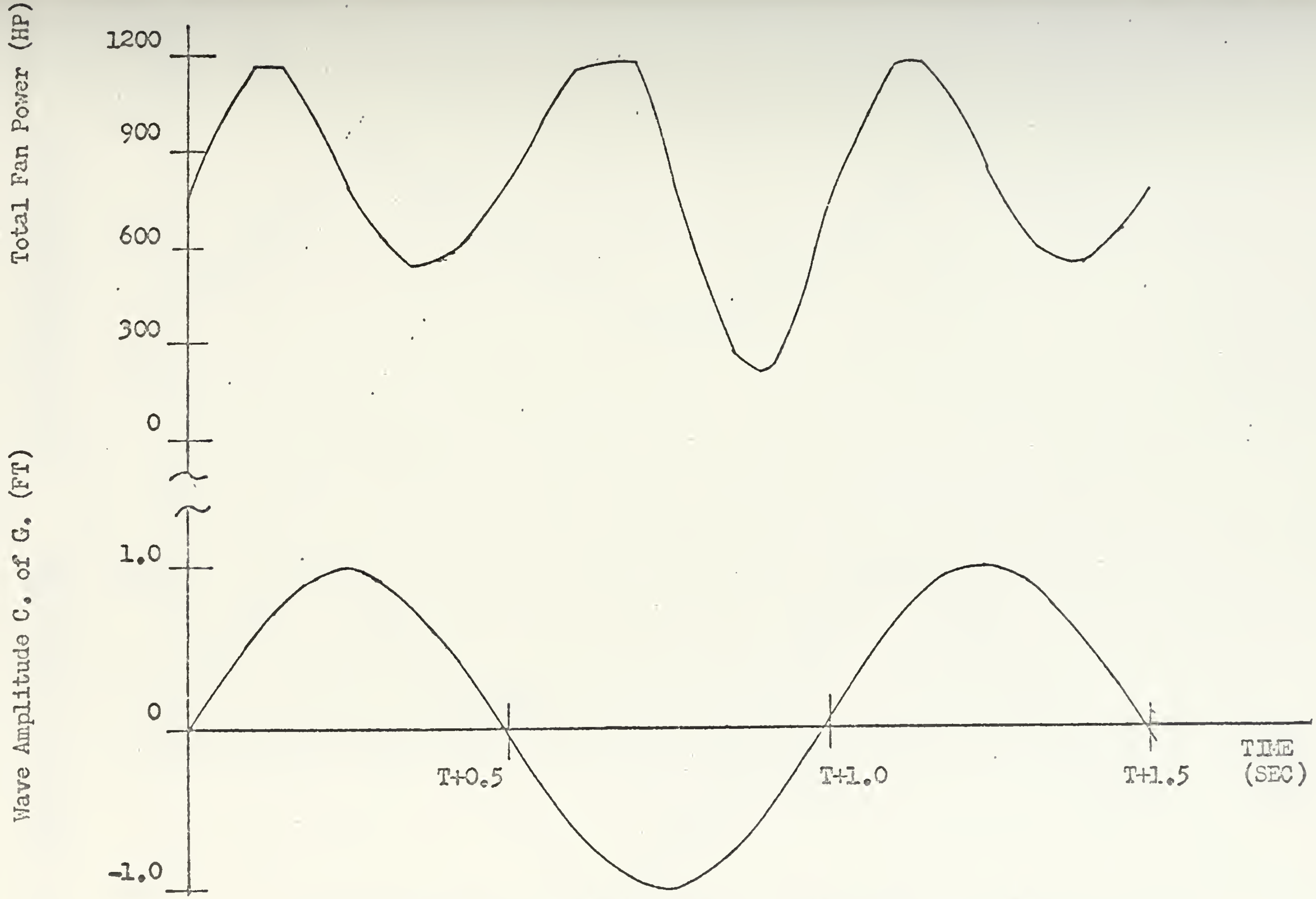


Figure 24. Total Fan Power Response to Ahead Wave

Initial Conditions: Speed 60 Knots, Wave Length 108 Feet, Wave Amplitude 1 Foot

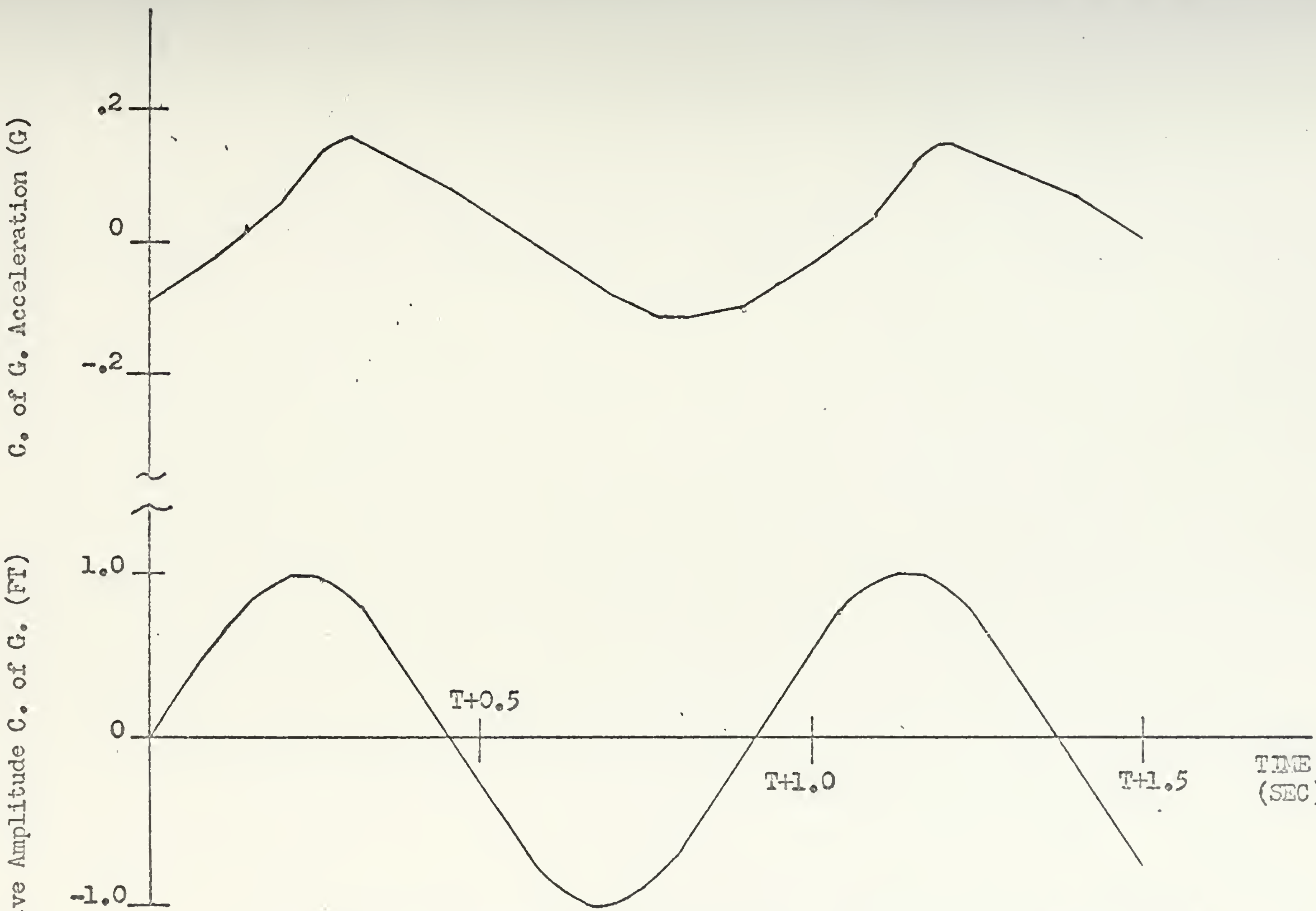


Figure 25. Response of Center of Gravity Acceleration to Astern Wave

Initial Conditions: Speed 60 Knots, Wave Length 72 Feet, Wave Amplitude 1 Foot

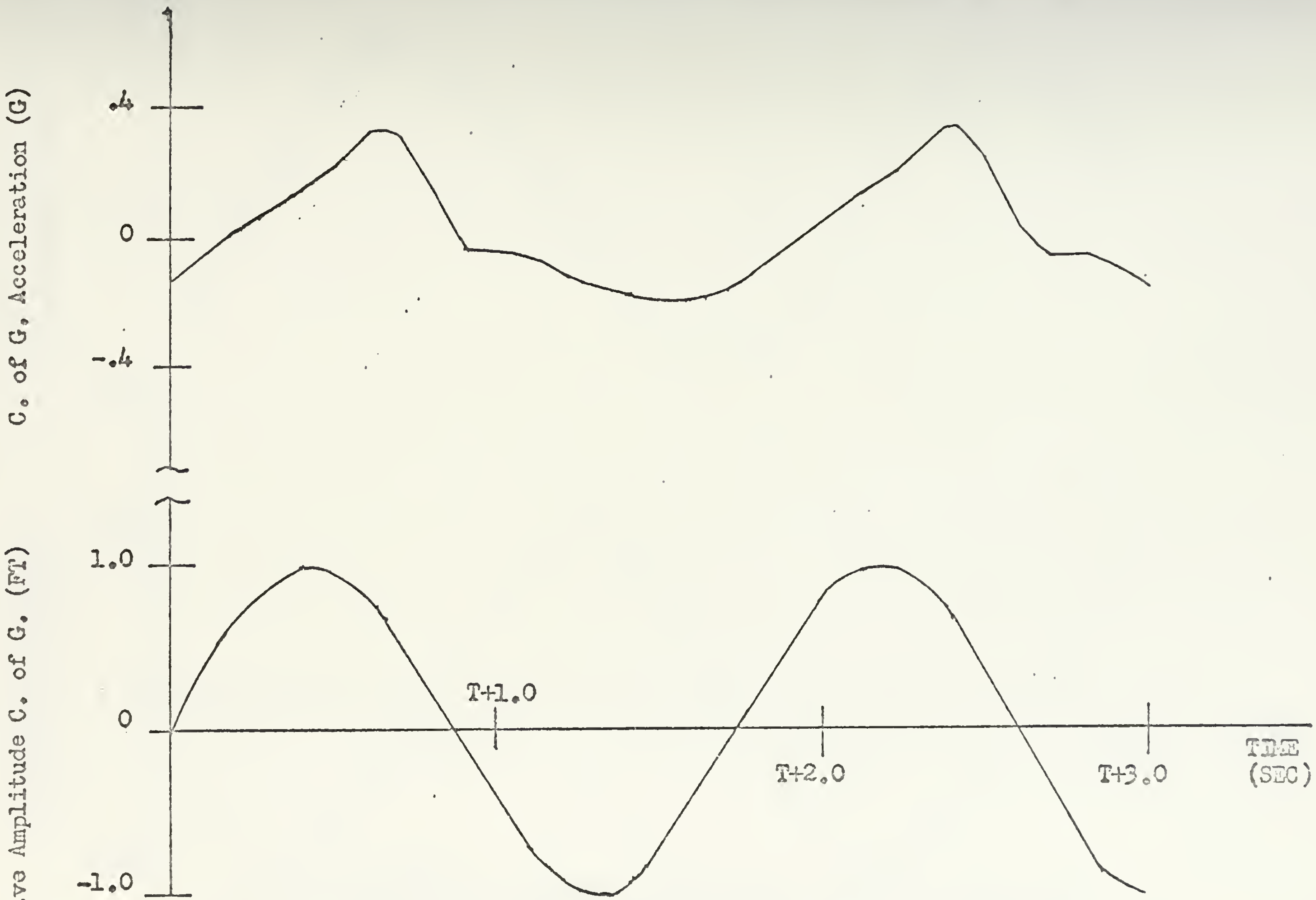


Figure 26. Response of Center of Gravity Acceleration to Astern Wave

Initial Conditions: Speed 60 Knots, Wave Length 108 Feet, Wave Amplitude 1 Foot

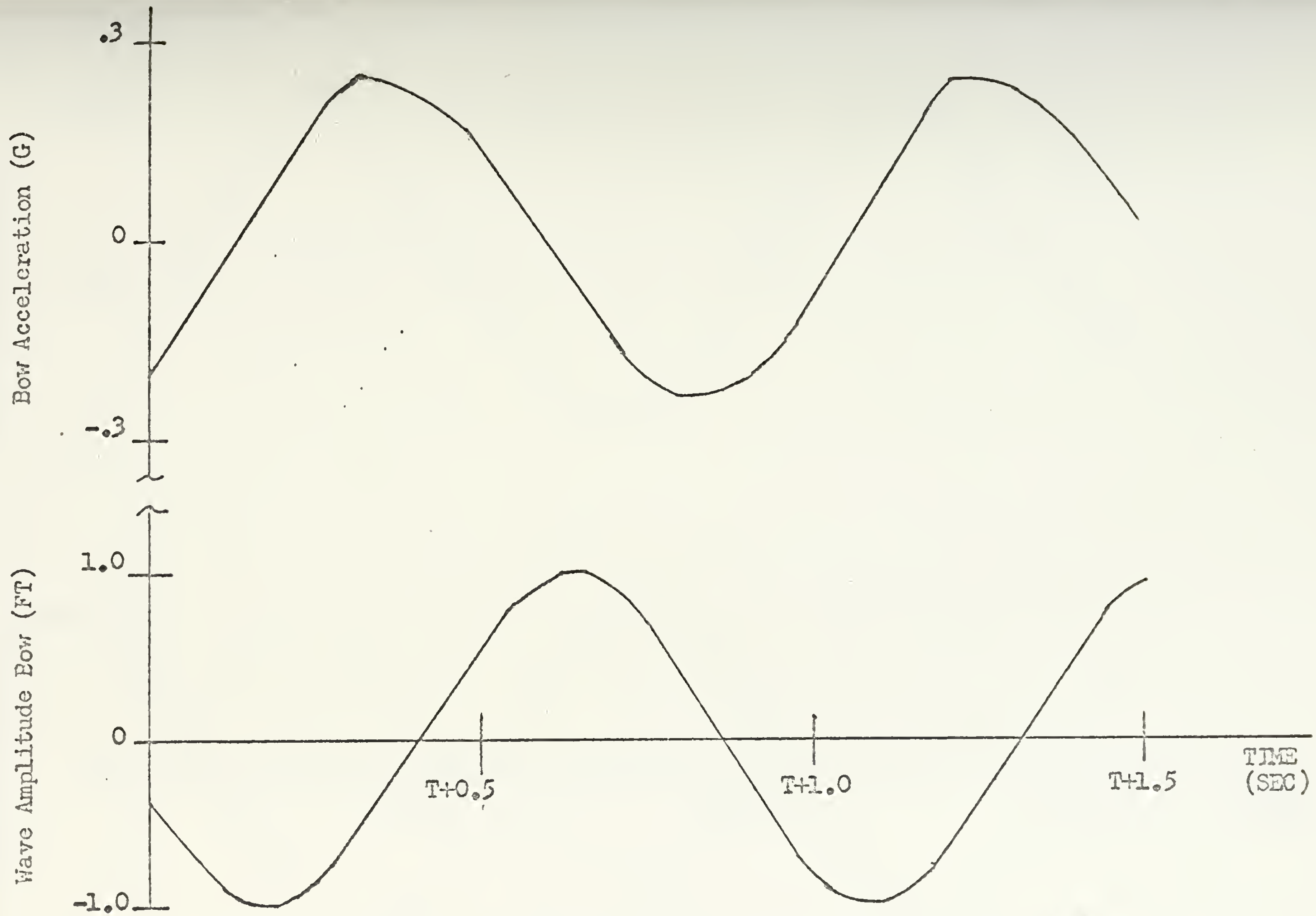


Figure 27. Response of Bow Acceleration to Astern Wave

Initial Conditions: Speed 60 Knots, Wave Length 72 Feet, Wave Amplitude 1 Foot

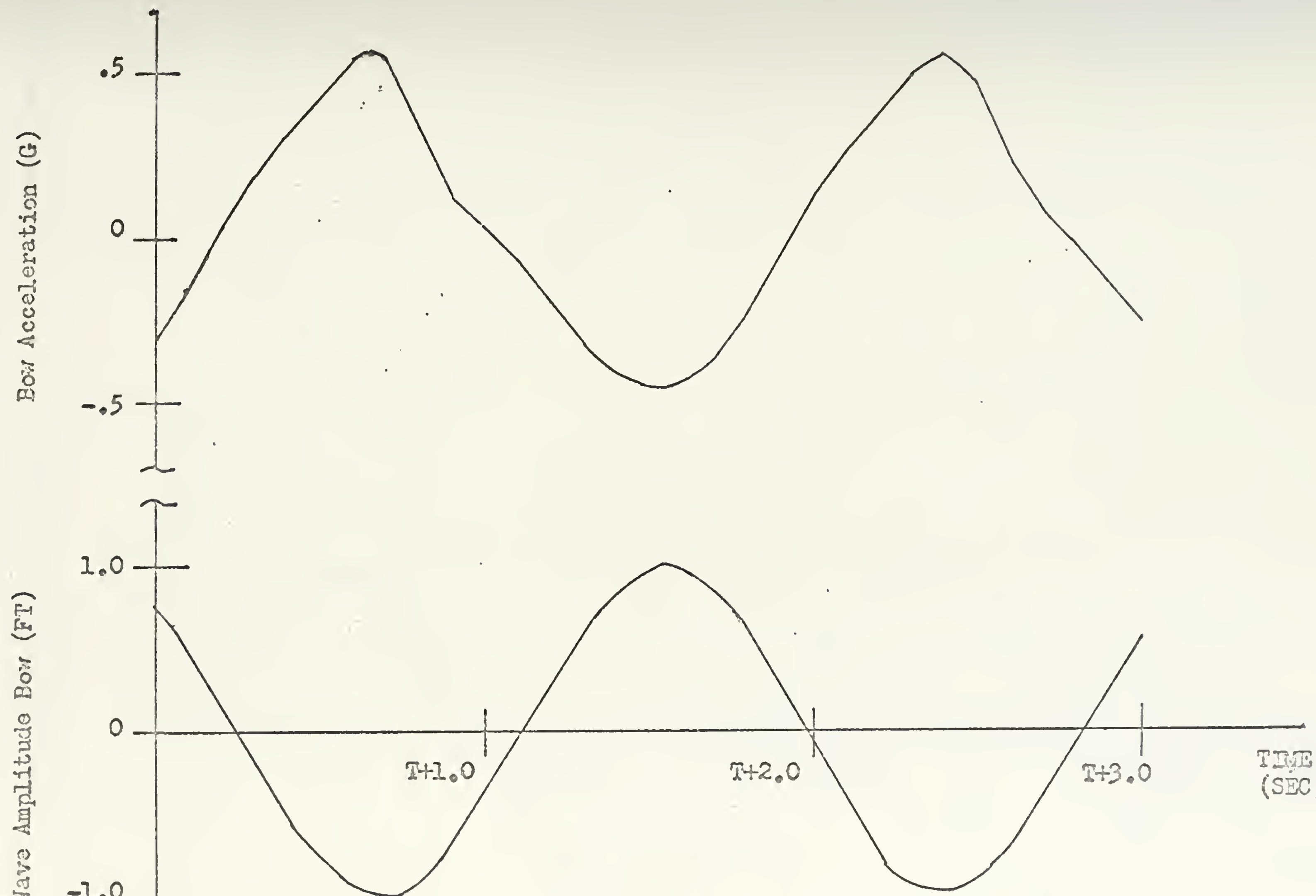


Figure 28. Response of Bow Acceleration to Astern Wave

Initial Conditions: Speed 60 Knots, Wave Length 108 Feet, Wave Amplitude 1 Foot

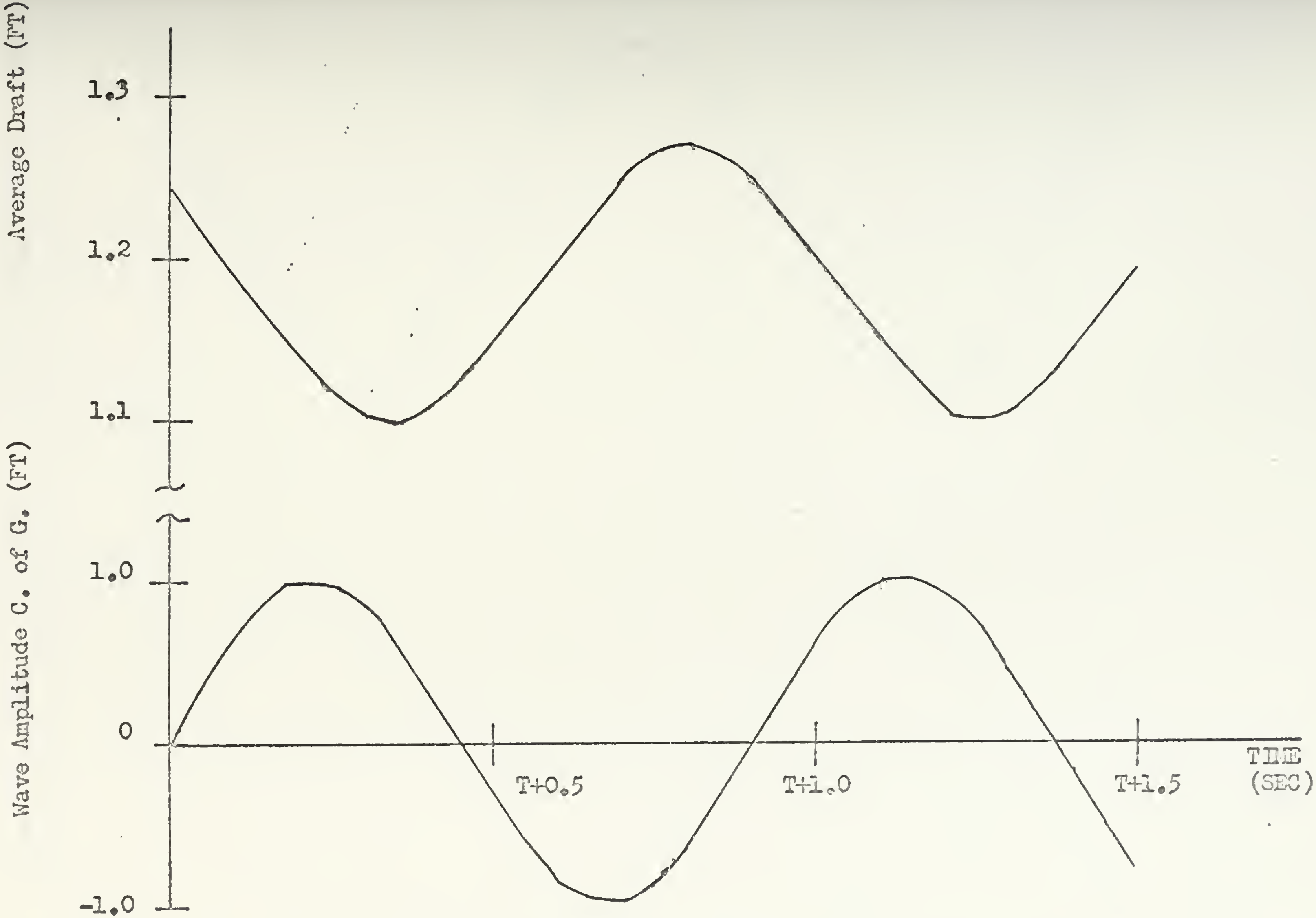


Figure 29. Draft Response to Astern Wave
Initial Conditions: Speed 60 Knots, Wave Length 72 Feet, Wave Amplitude 1 Foot, Draft 1.033 Feet

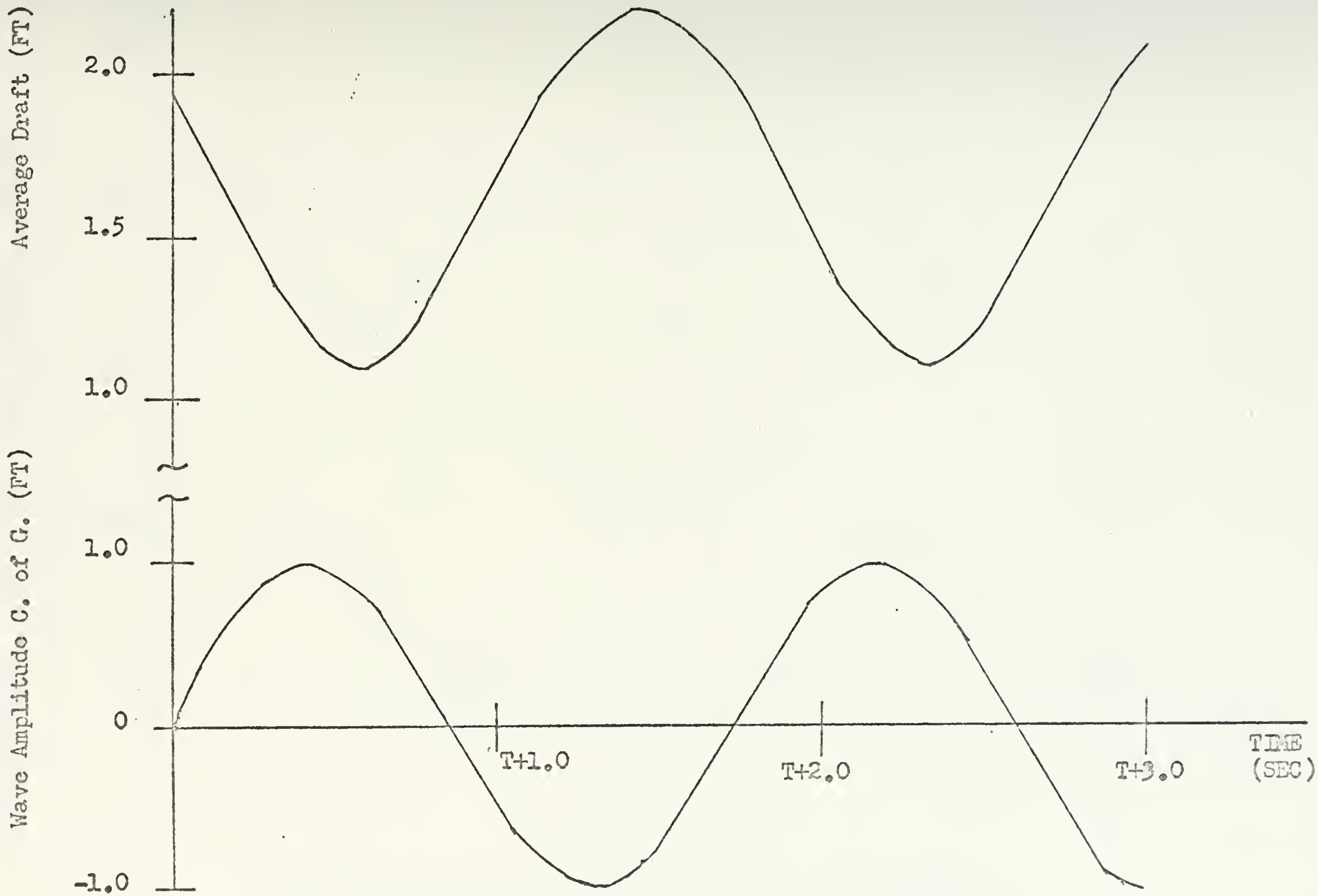


Figure 30. Draft Response to Astern Wave
Initial Conditions: Speed 60 Knots, Wave Length 108 Feet, Wave Amplitude 1 Foot, Draft 1.033 Feet

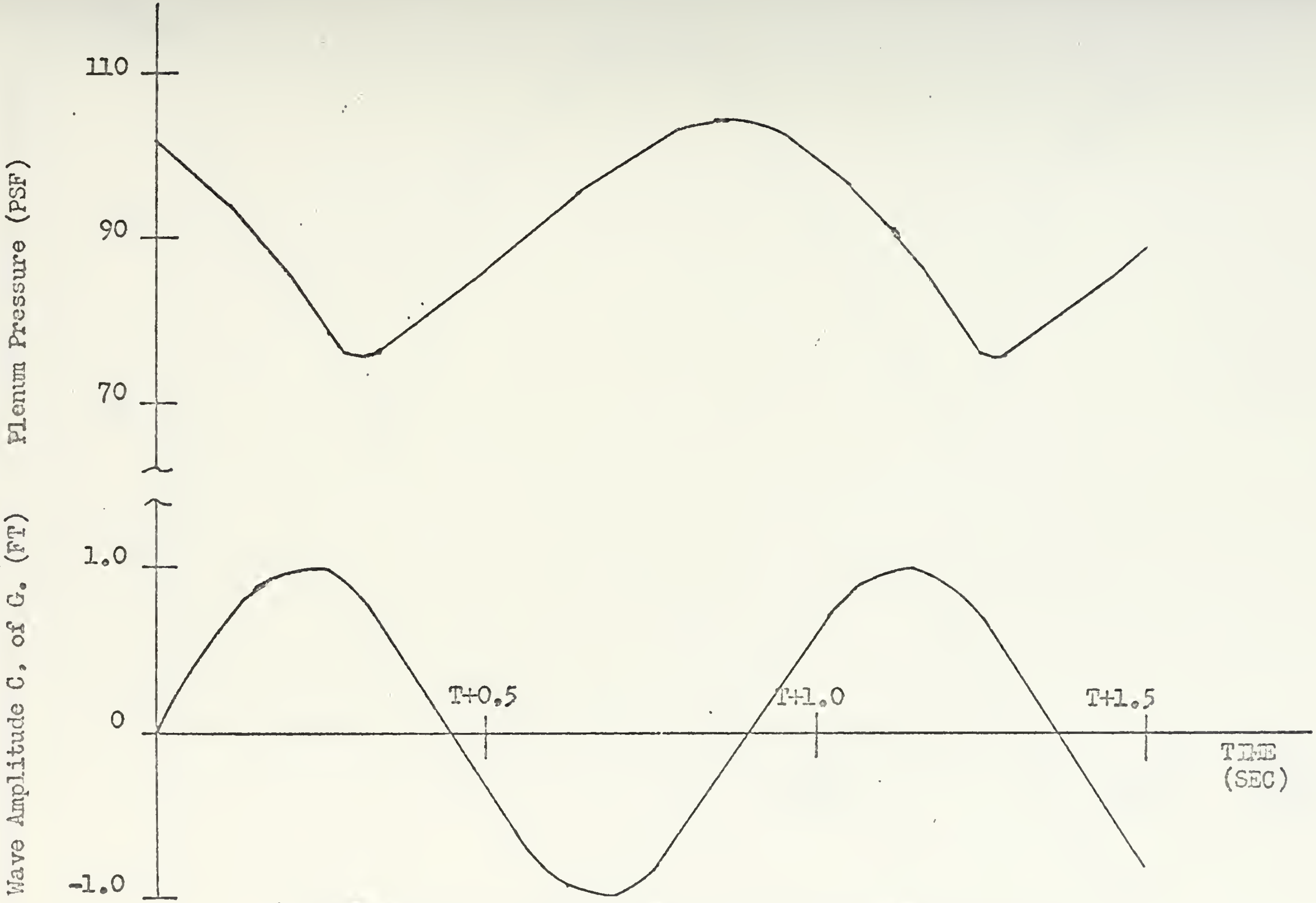


Figure 31. Response of Plenum Pressure to Astern Wave

Initial Conditions: Speed 60 Knots, Wave Length 72 Feet, Wave Amplitude 1 Foot, Plenum Pressure 92.8 (PSF)

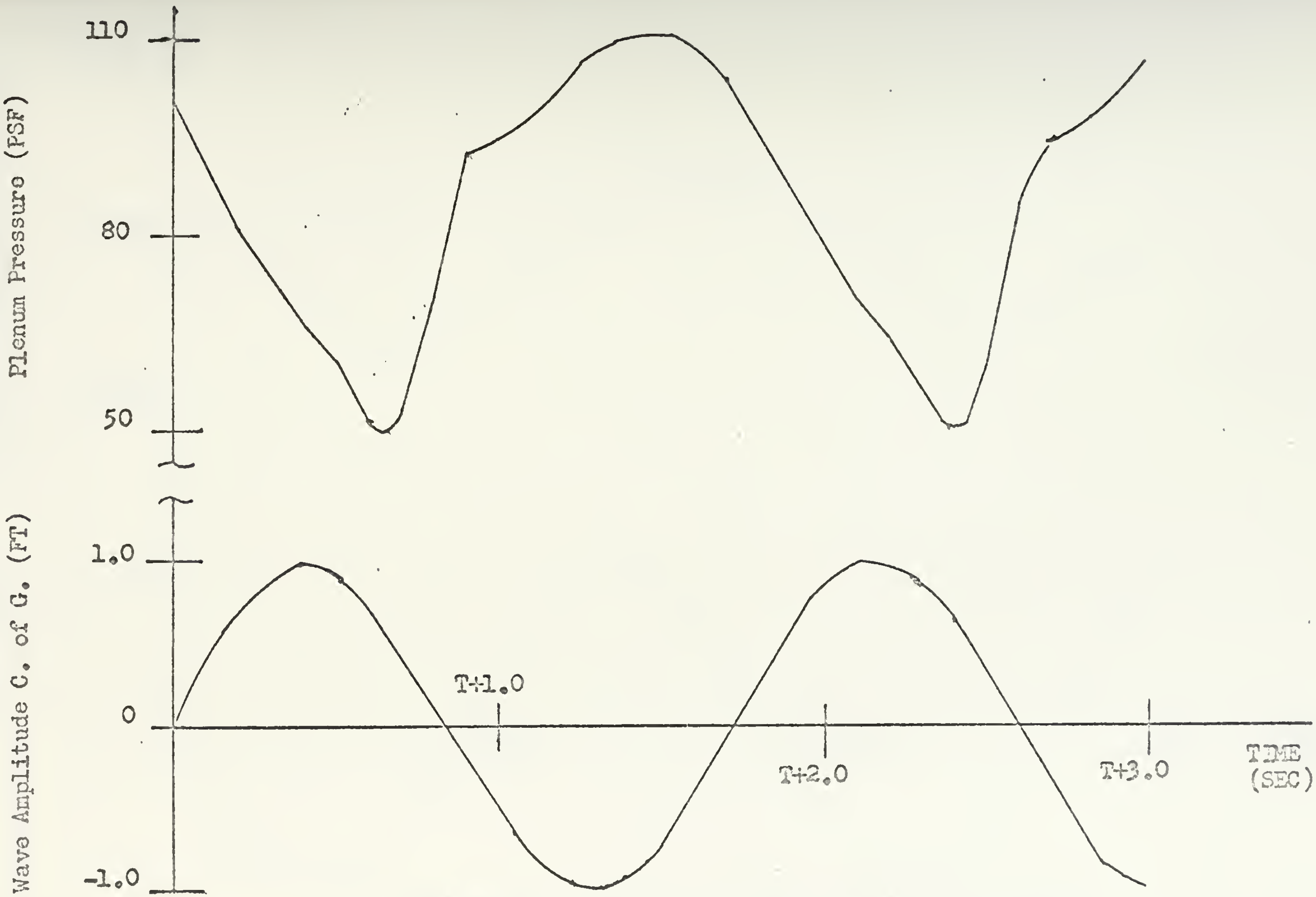


Figure 32. Response of Plenum Pressure to Astern Wave

Initial Conditions: Speed 60 Knots, Wave Length 103 Feet, Wave Amplitude 1 Foot, Plenum Pressure 92.8 PSF

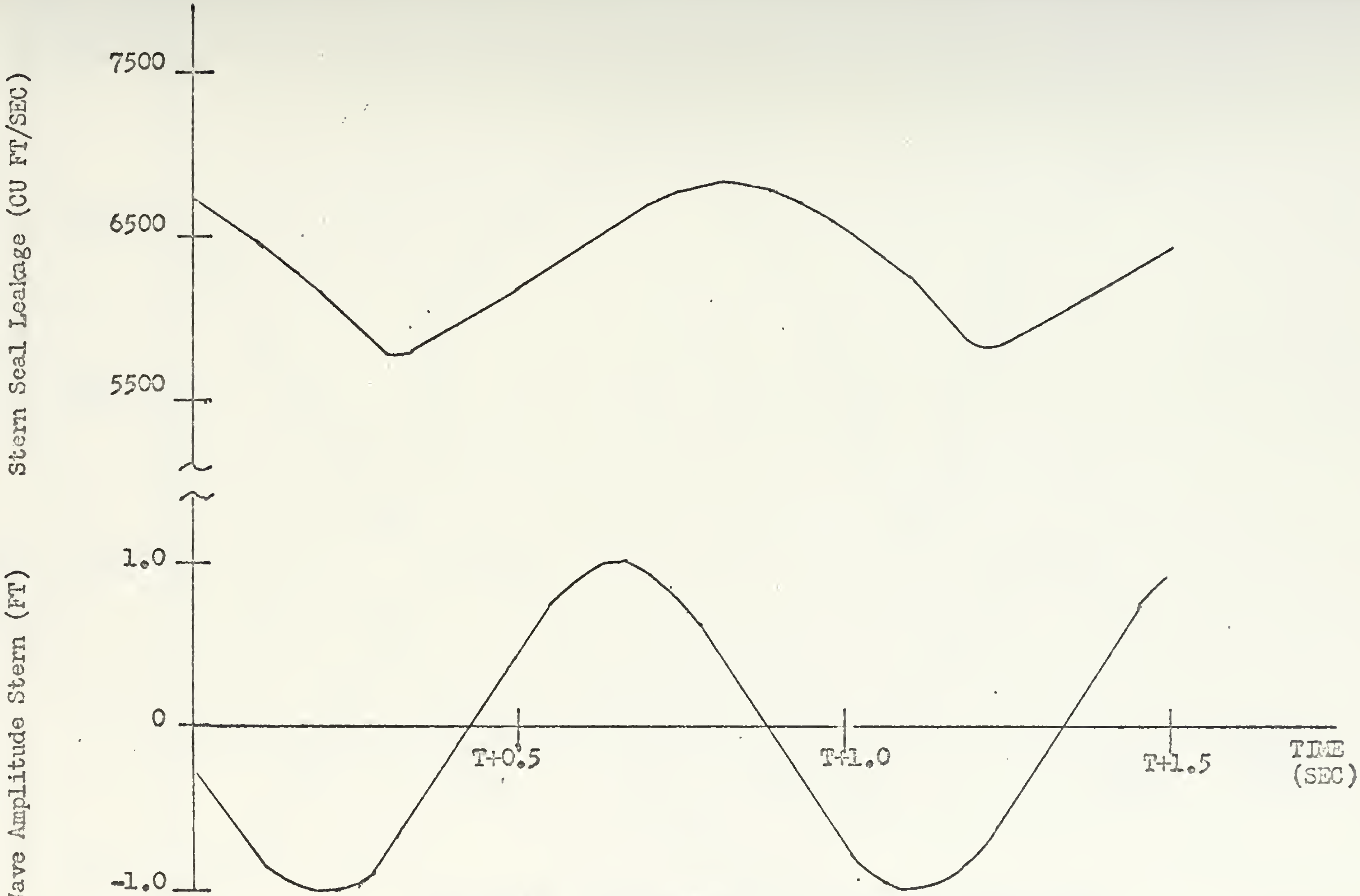


Figure 33. Stern Seal Leakage Rate for Astern Wave

Initial Conditions: Speed 60 Knots, Wave Length 72 Feet, Wave Amplitude 1 Foot, Stern Seal Leakage 6417 Cubic Feet/Second

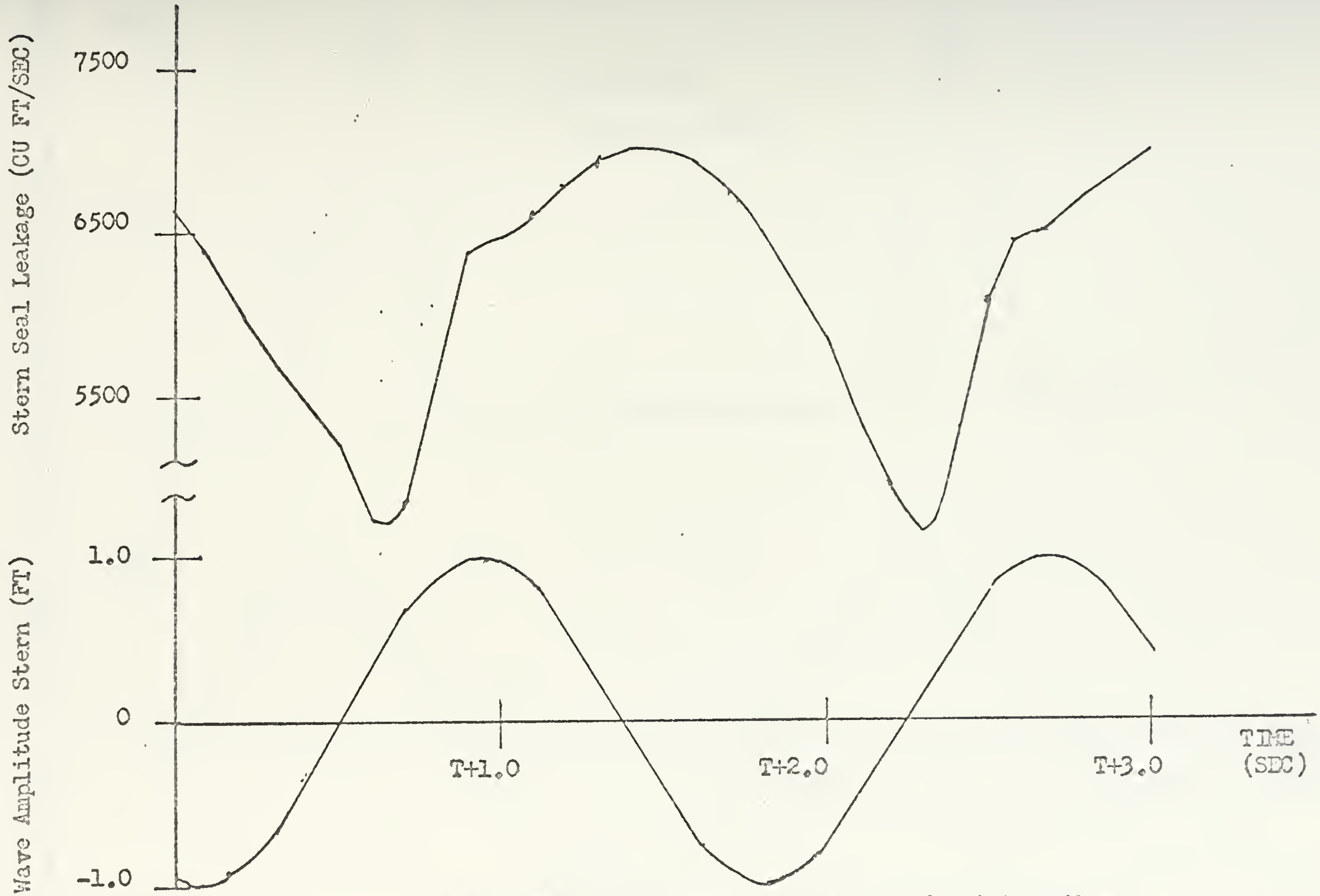


Figure 34. Stern Seal Leakage Rate for Astern Wave

Initial Conditions: Speed 60 Knots, Wave Length 103 Feet, Wave Amplitude 1 Foot, Stern Seal Leakage Rate 6417 Cubic Feet/Second

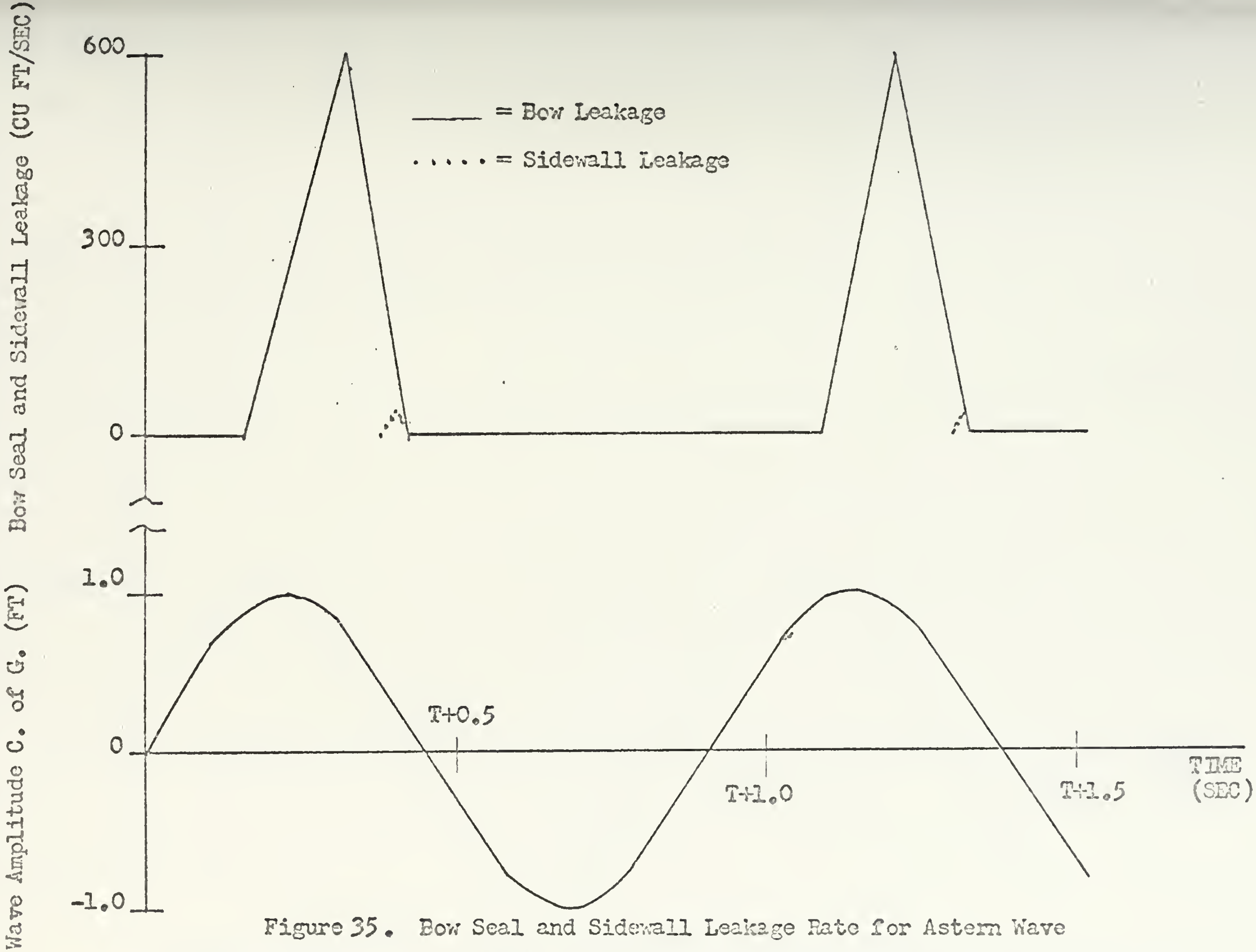


Figure 35. Bow Seal and Sidewall Leakage Rate for Astern Wave
Initial Conditions: Speed 60 Knots, Wave Length 72 Feet, Wave Amplitude 1 Foot

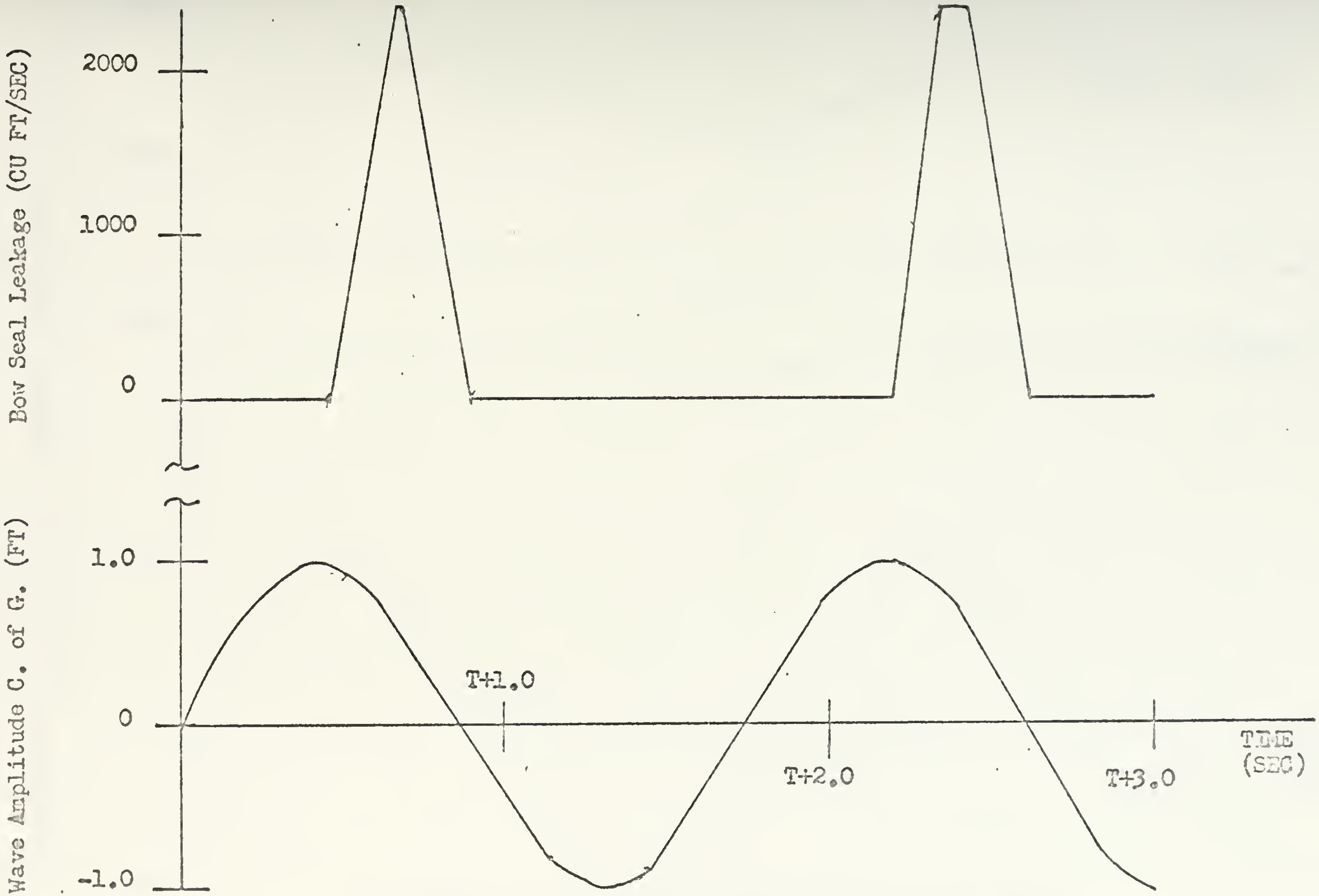


Figure 36. Bow Seal Leakage Rate for Astern Wave

Initial Condition: Speed 60 Knots, Wave Length 108 Feet, Wave Amplitude 1 Foot

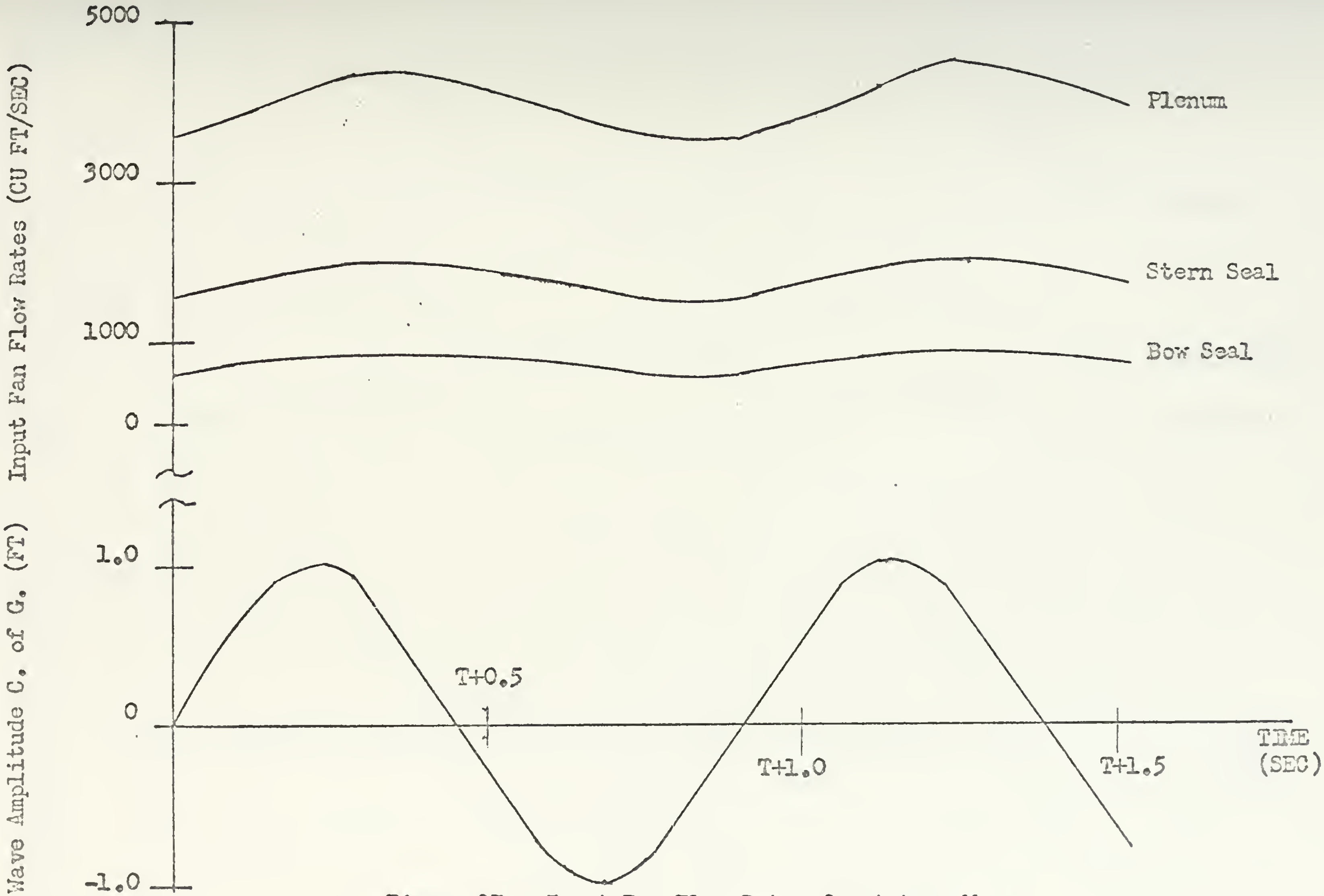


Figure 37. Input Fan Flow Rates for Astern Wave

Initial Conditions: Speed 60 Knots, Wave Length 72 Feet, Wave Amplitude 1 Foot

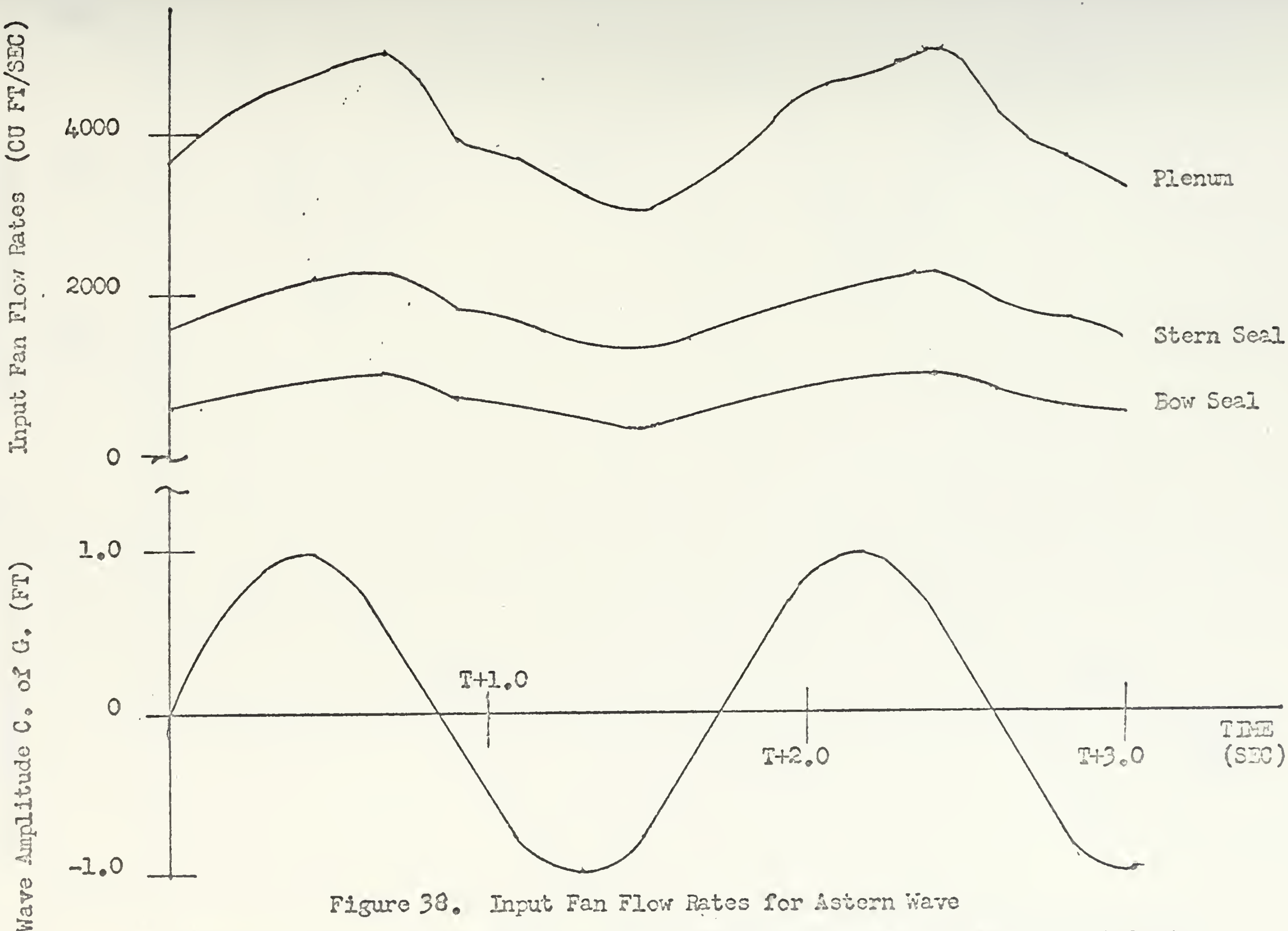


Figure 38. Input Fan Flow Rates for Astern Wave

Initial Conditions: Speed 60 Knots, Wave Length 108 Feet, Wave Amplitude 1 Foot

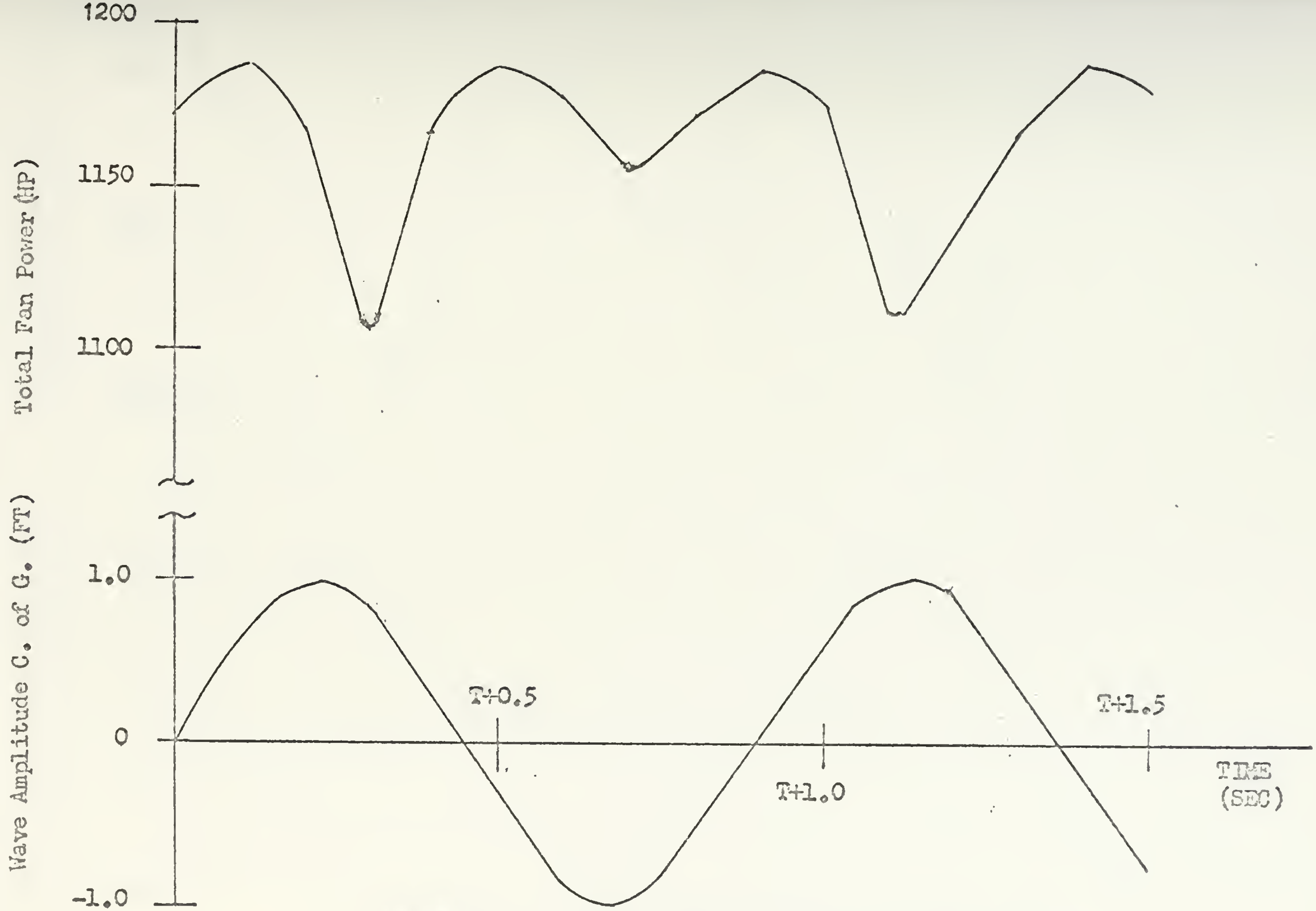


Figure 39. Total Fan Power Response to Astern Wave

Initial Conditions: Speed 60 Knots, Wave Length 72 Feet, Wave Amplitude 1 Foot

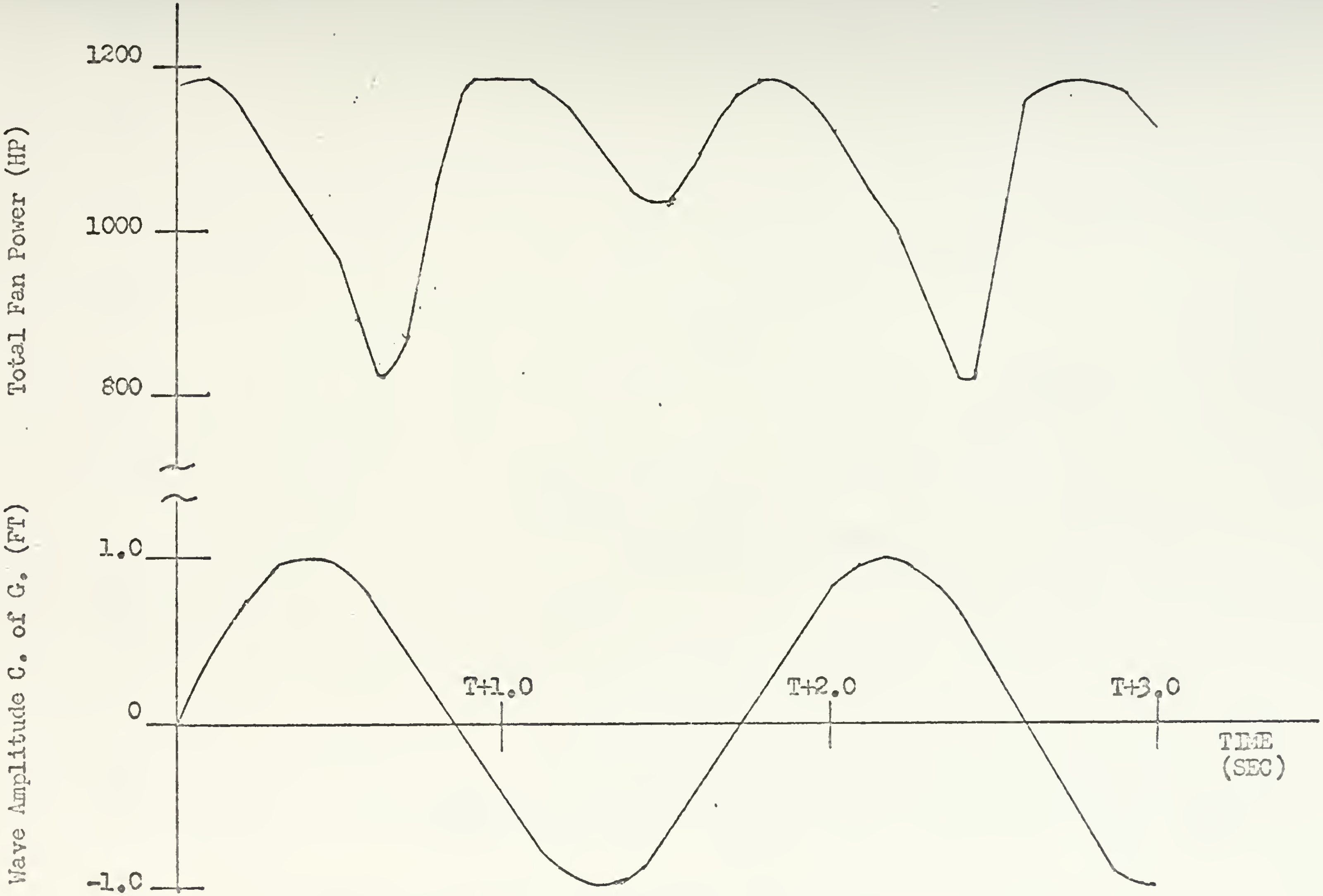


Figure 40. Total Fan Power Response to Astern Wave

Initial Conditions: Speed 60 Knots, Wave Length 108 Feet, Wave Amplitude 1 Foot

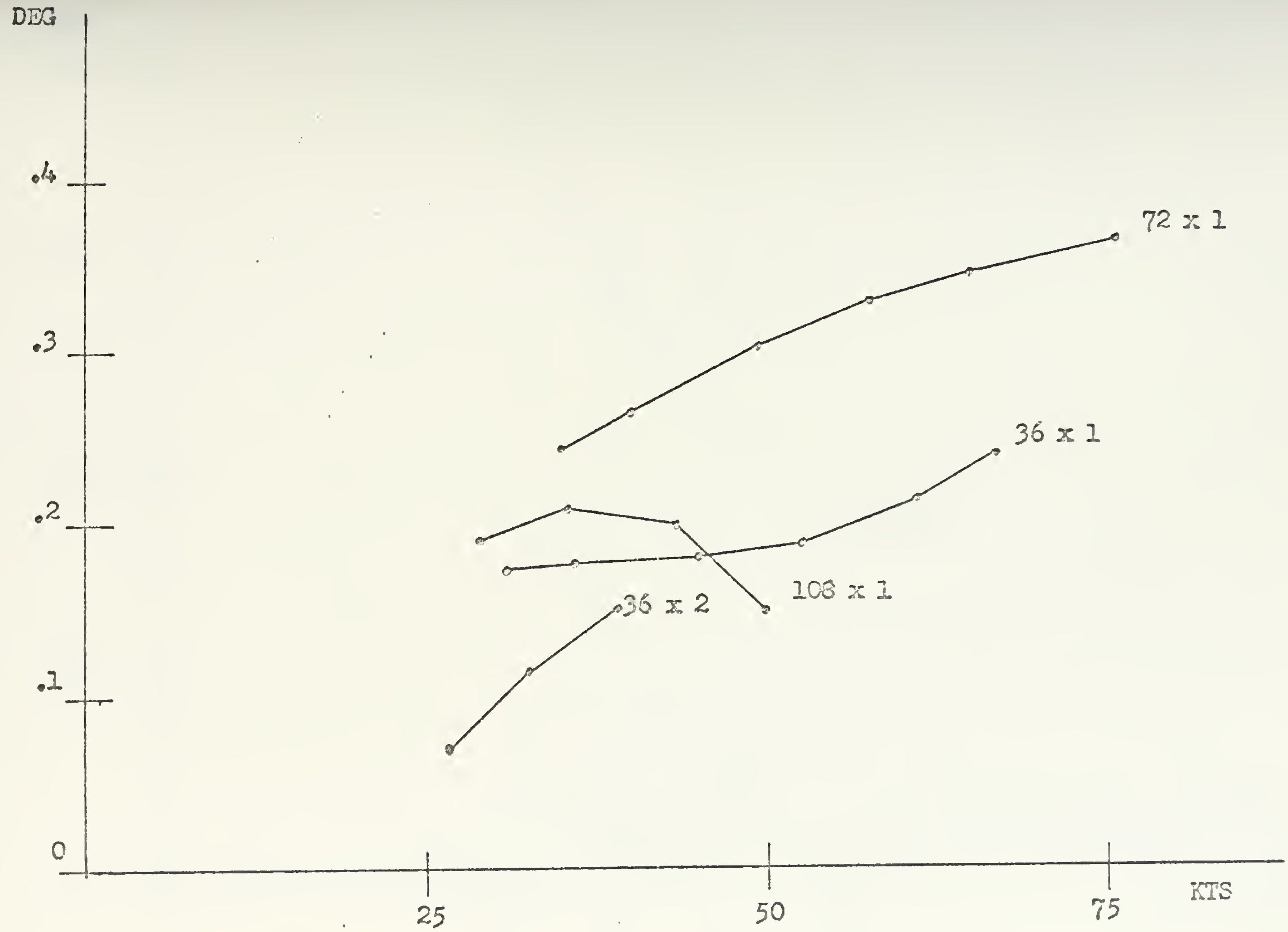


Figure 41. Average Pitch Angle Versus Steady-State
Speed for Different Ahead Wave Conditions

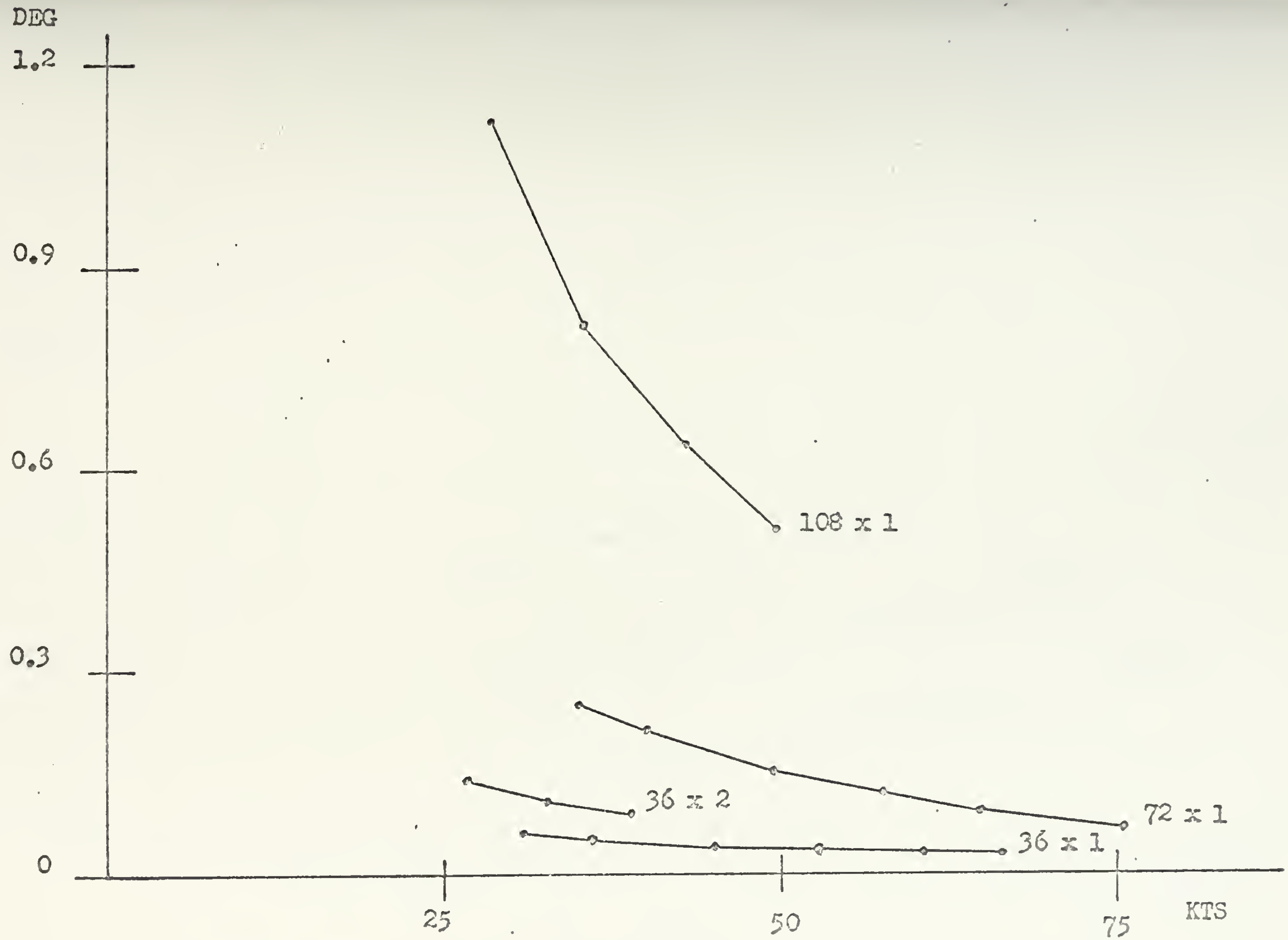


Figure 42. Fluctuation of Pitch Angle Versus Steady-State Speed for Different Ahead Wave Conditions

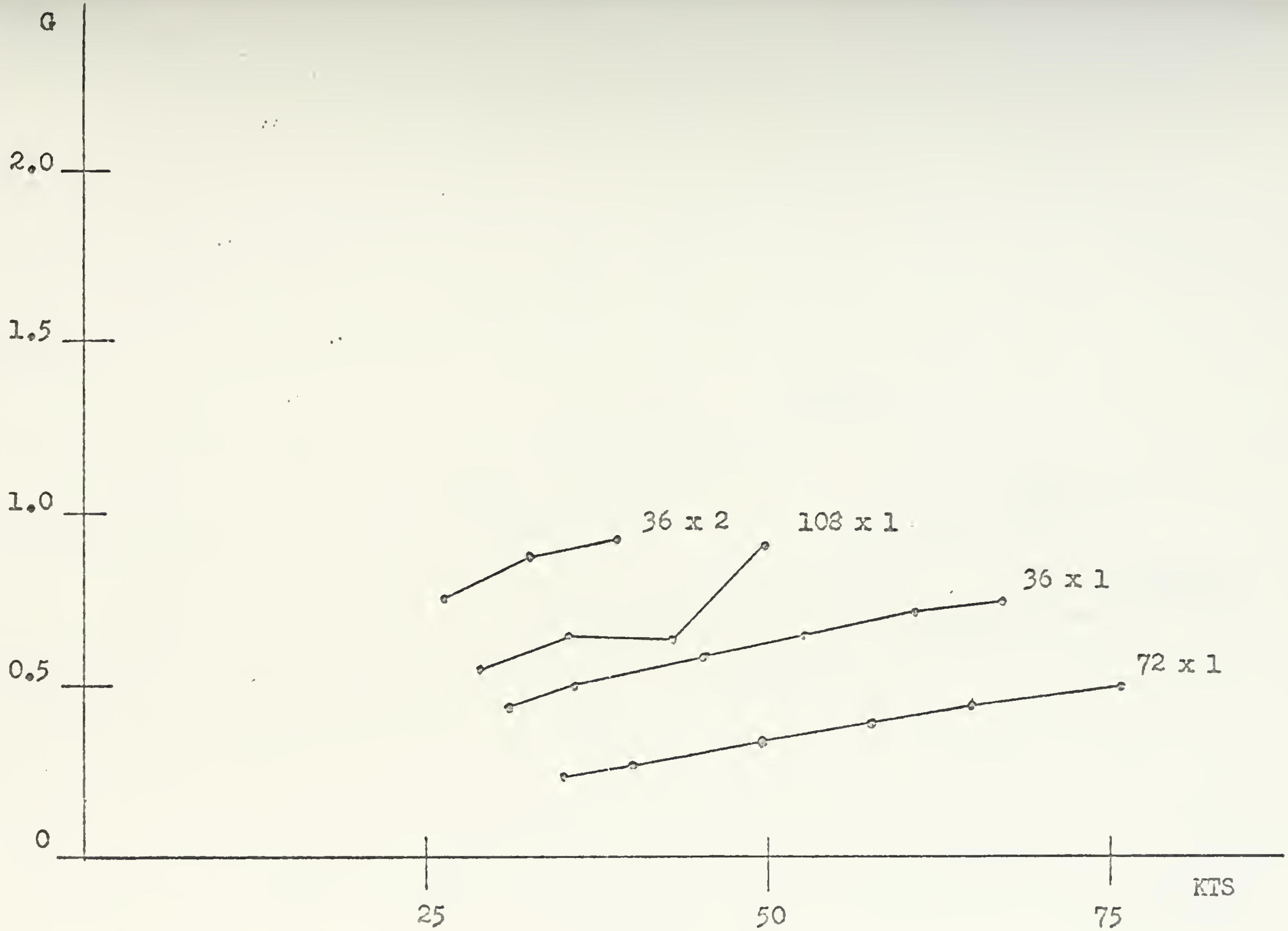


Figure 43. Fluctuation of Center of Gravity Acceleration Versus Steady-State Speed for Different Ahead Wave Conditions

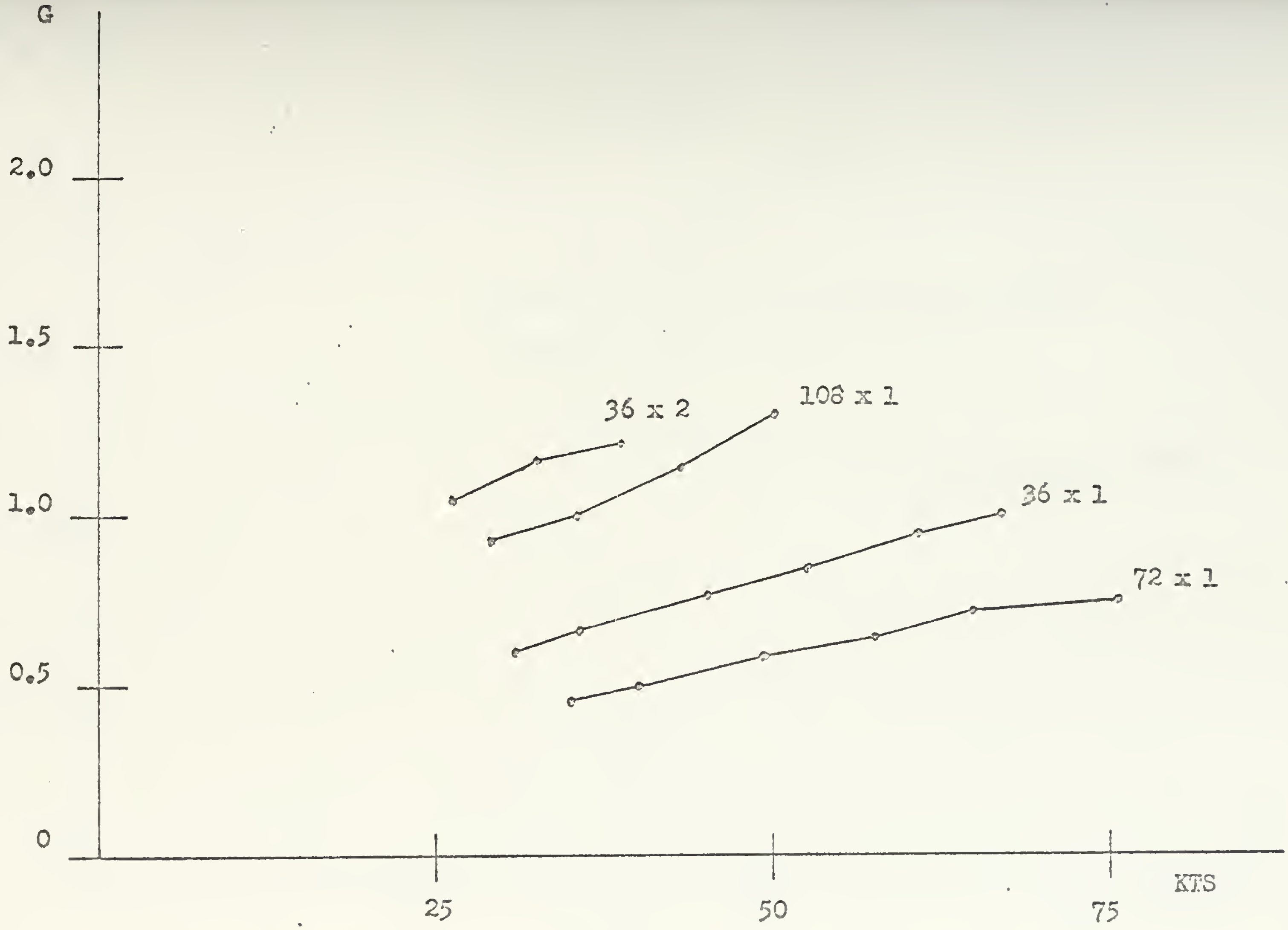


Figure 44. Fluctuation of Bow Acceleration Versus Steady-State Speed for Different Ahead Wave Conditions

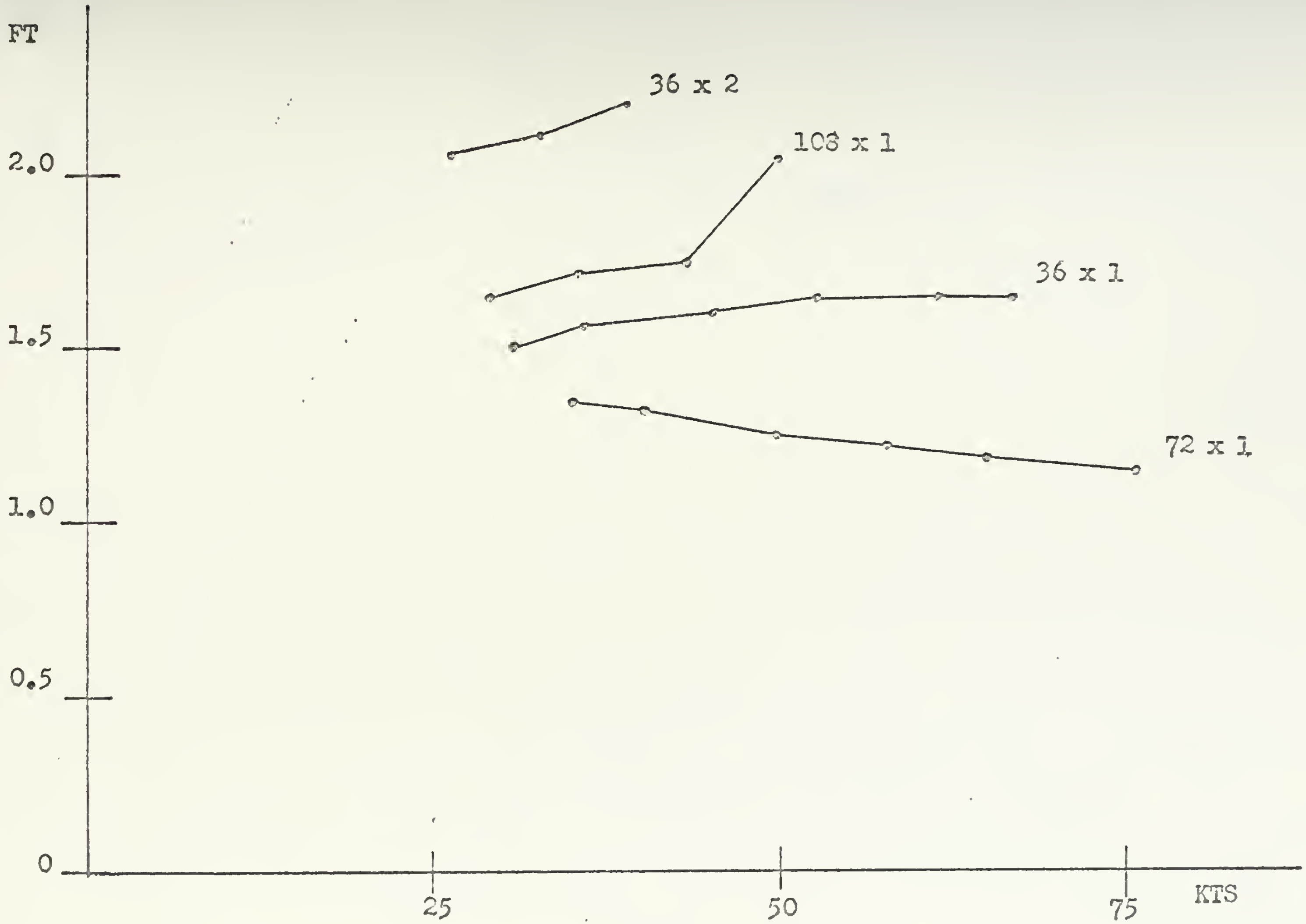


Figure 45. Average Draft Versus Steady-State Speed
for Different Ahead Wave Conditions

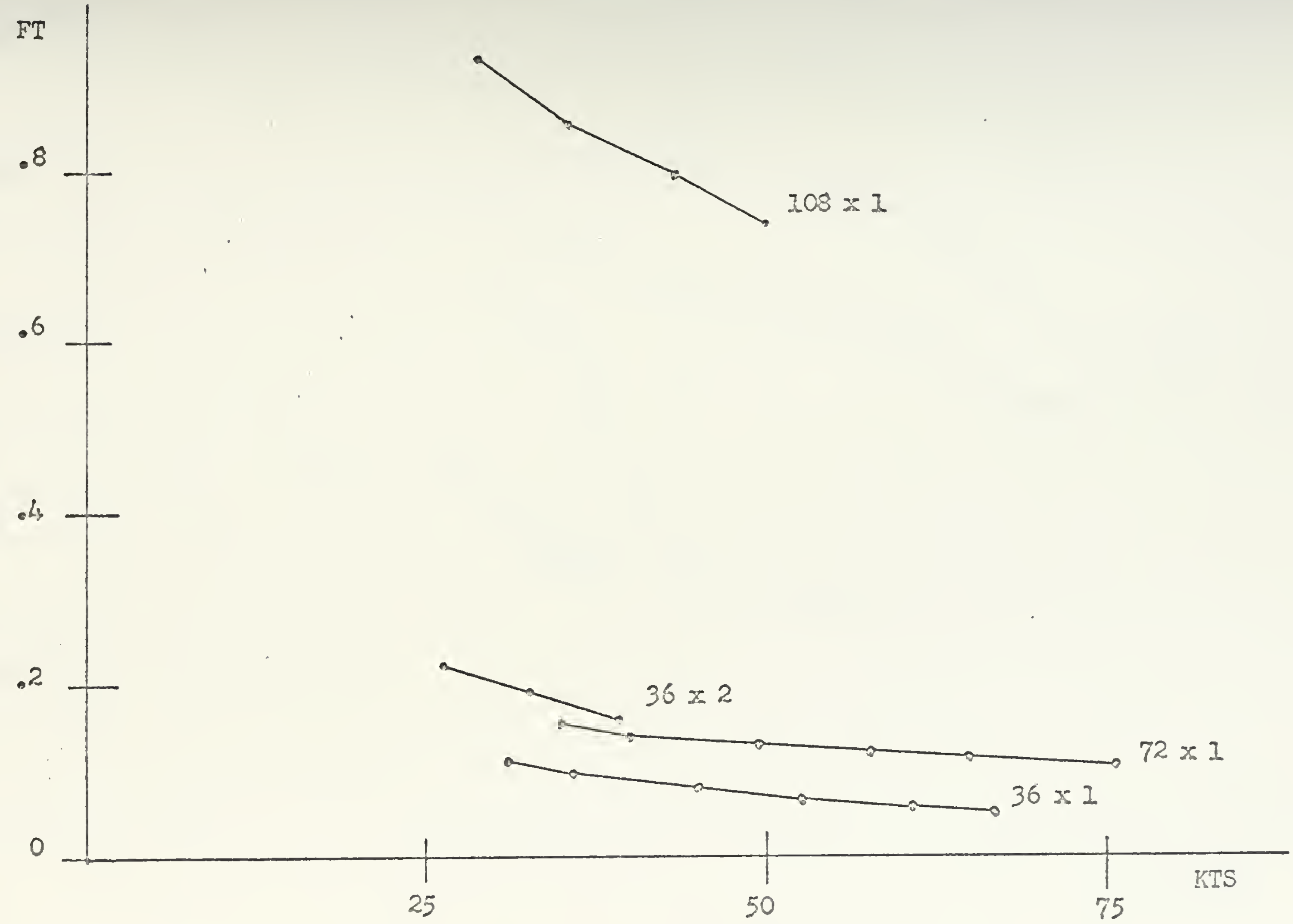


Figure 46. Fluctuation of Draft Versus Steady-State Speed for Different Ahead Wave Conditions

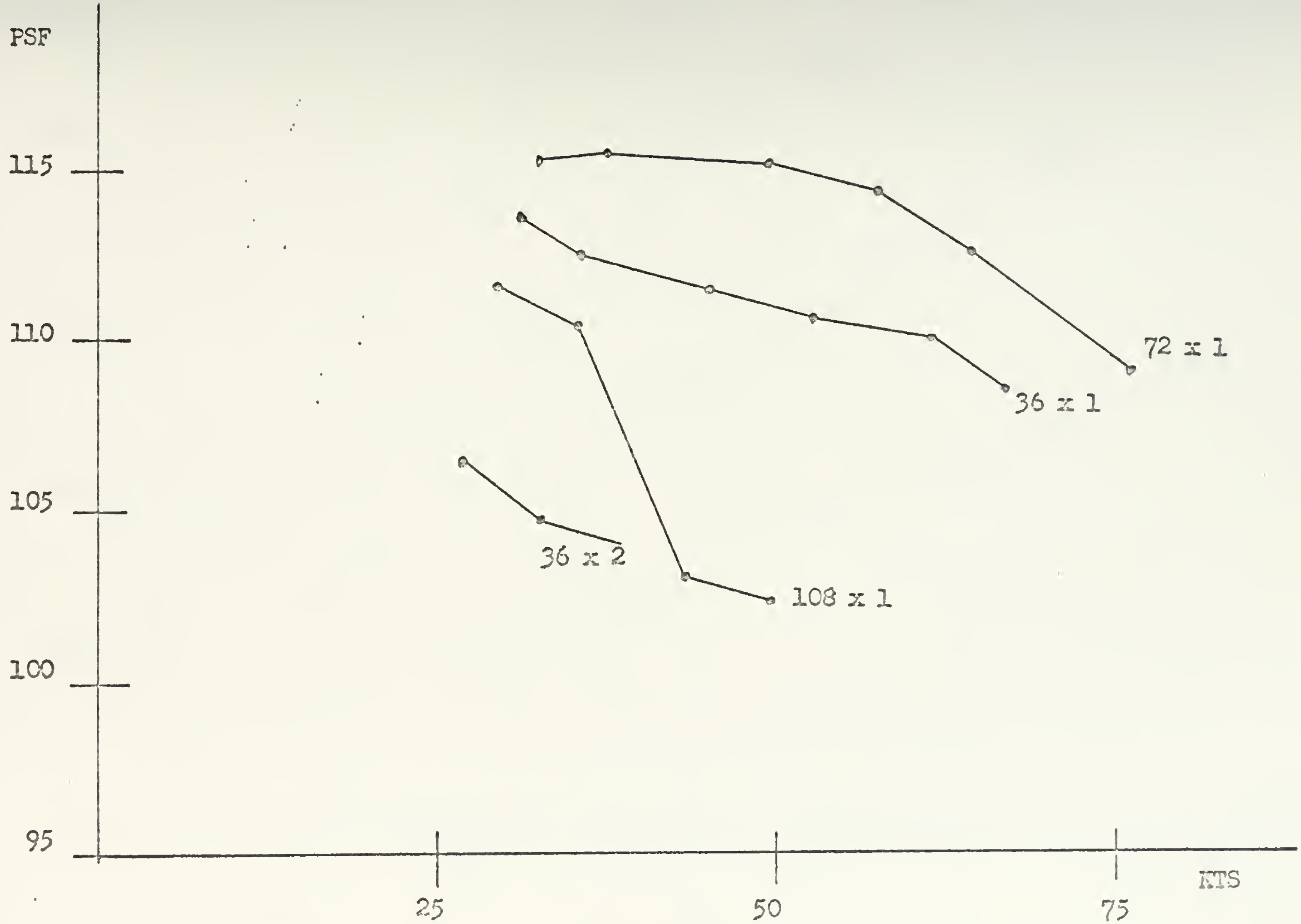


Figure 47. Average Bow Seal and Stern Seal Pressure Versus Steady-State Speed for Different Ahead Wave Conditions

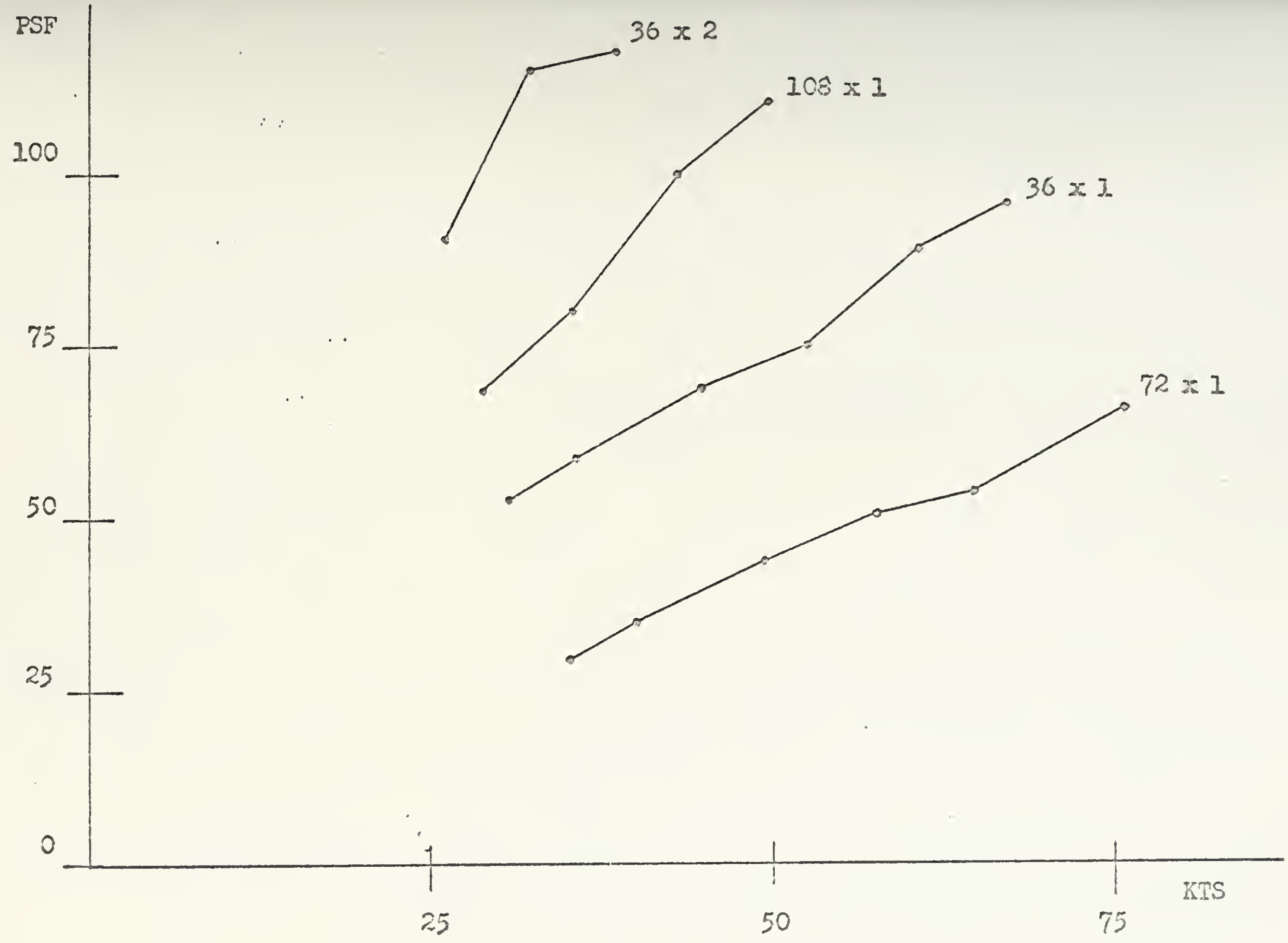


Figure 48. Fluctuation of Bow Seal and Stern Seal Pressure Versus Steady-State Speed for Different Ahead Wave Conditions

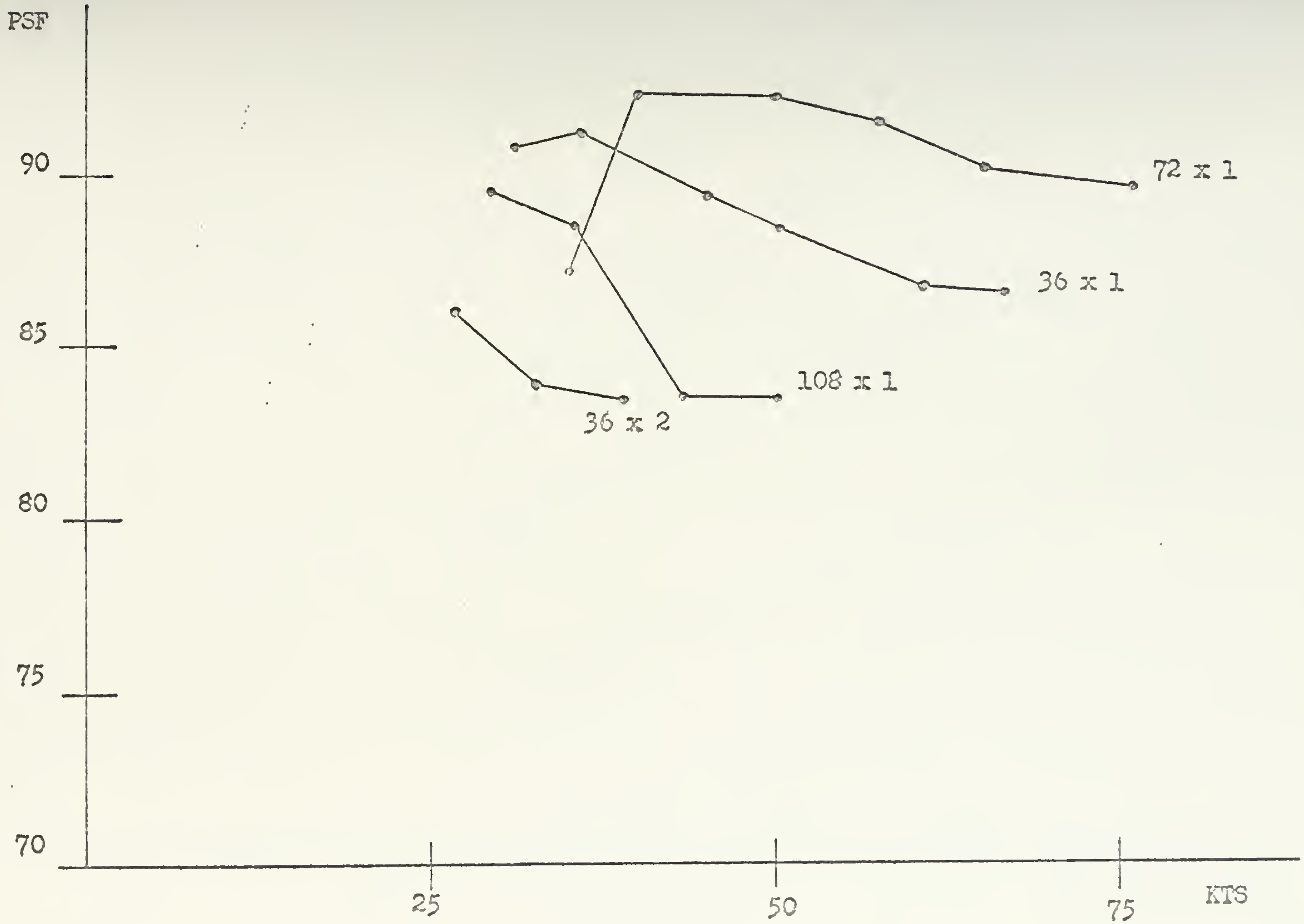


Figure 49. Average Plenum Pressure Versus Steady-State Speed for Different Ahead Wave Conditions

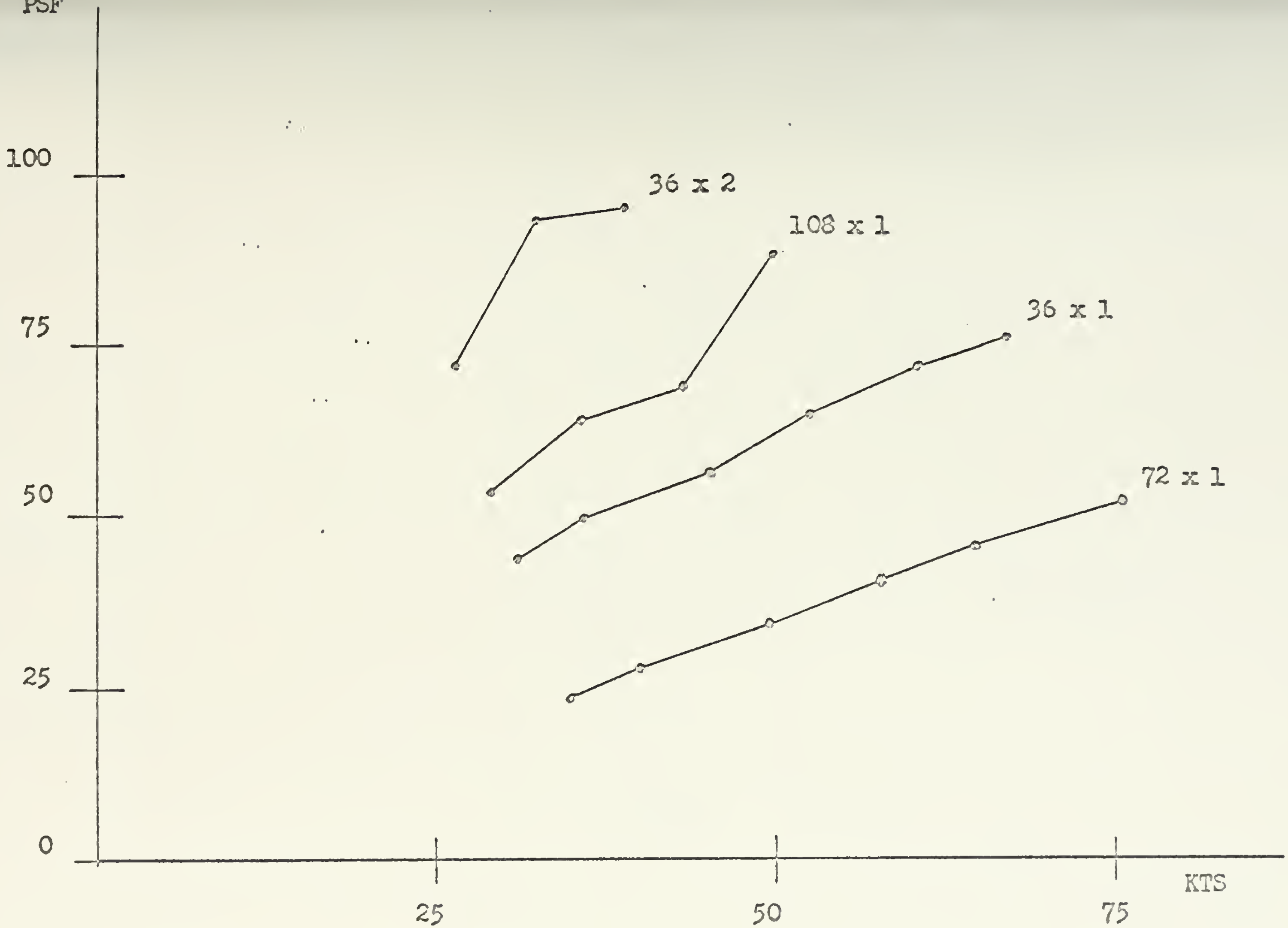


Figure 50. Fluctuation of Plenum Pressure Versus Steady-State Speed for Different Ahead Wave Conditions

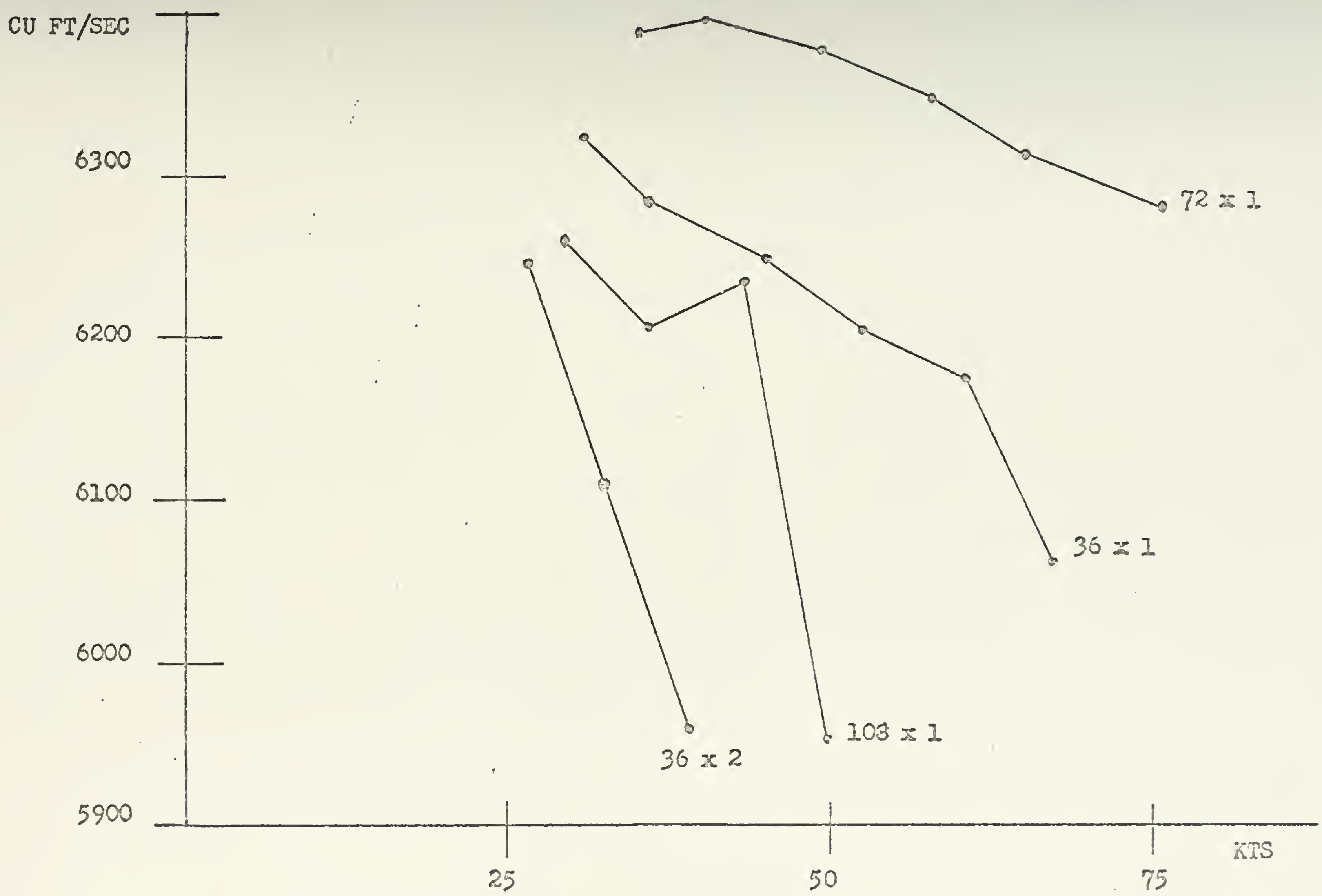


Figure 51. Average Stern Seal Leakage Rate Versus Steady-State Speed for Different Ahead Wave Conditions

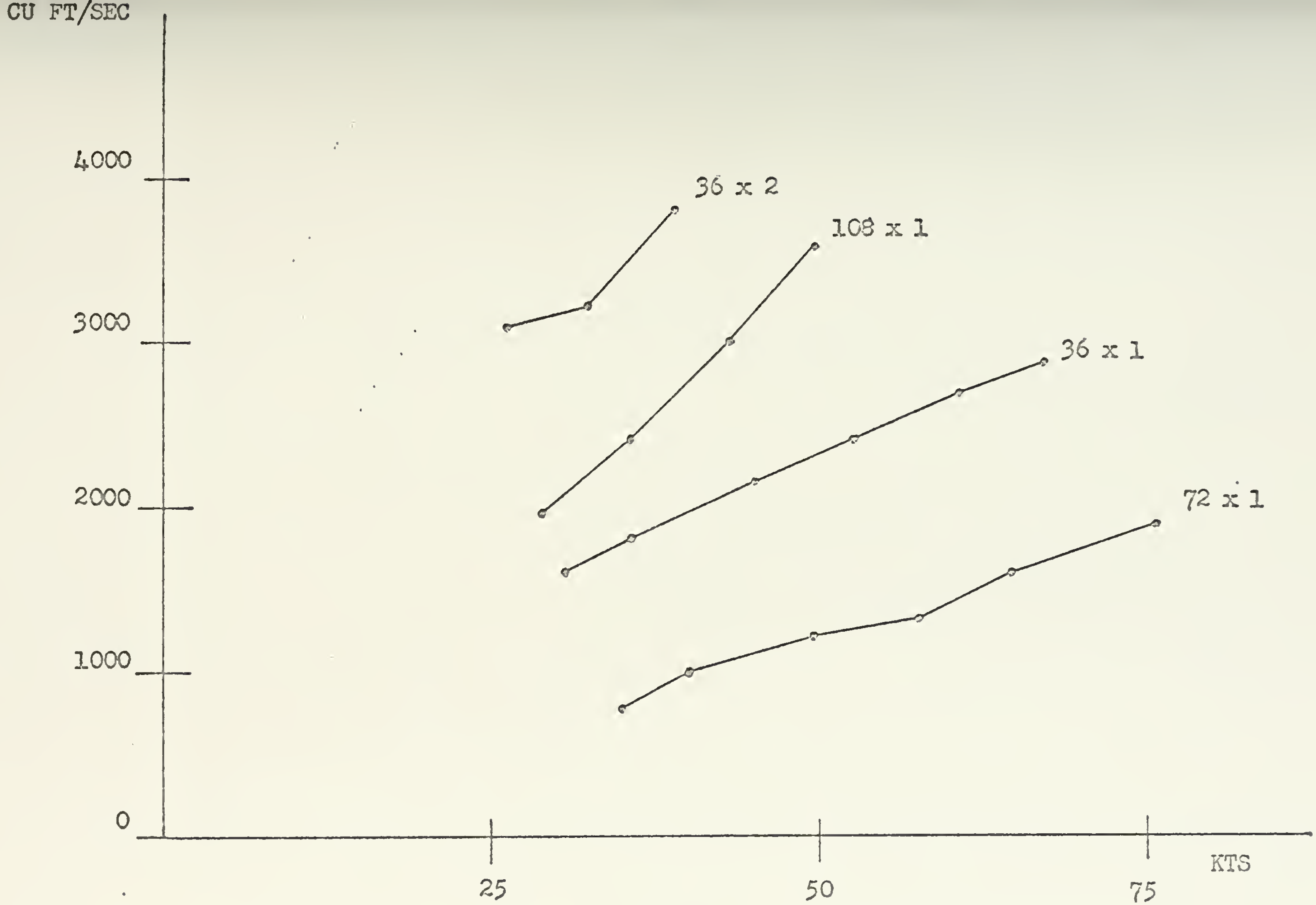


Figure 52. Fluctuation of Stern Seal Leakage Rate Versus Steady-State Speed for Different Ahead Wave Conditions

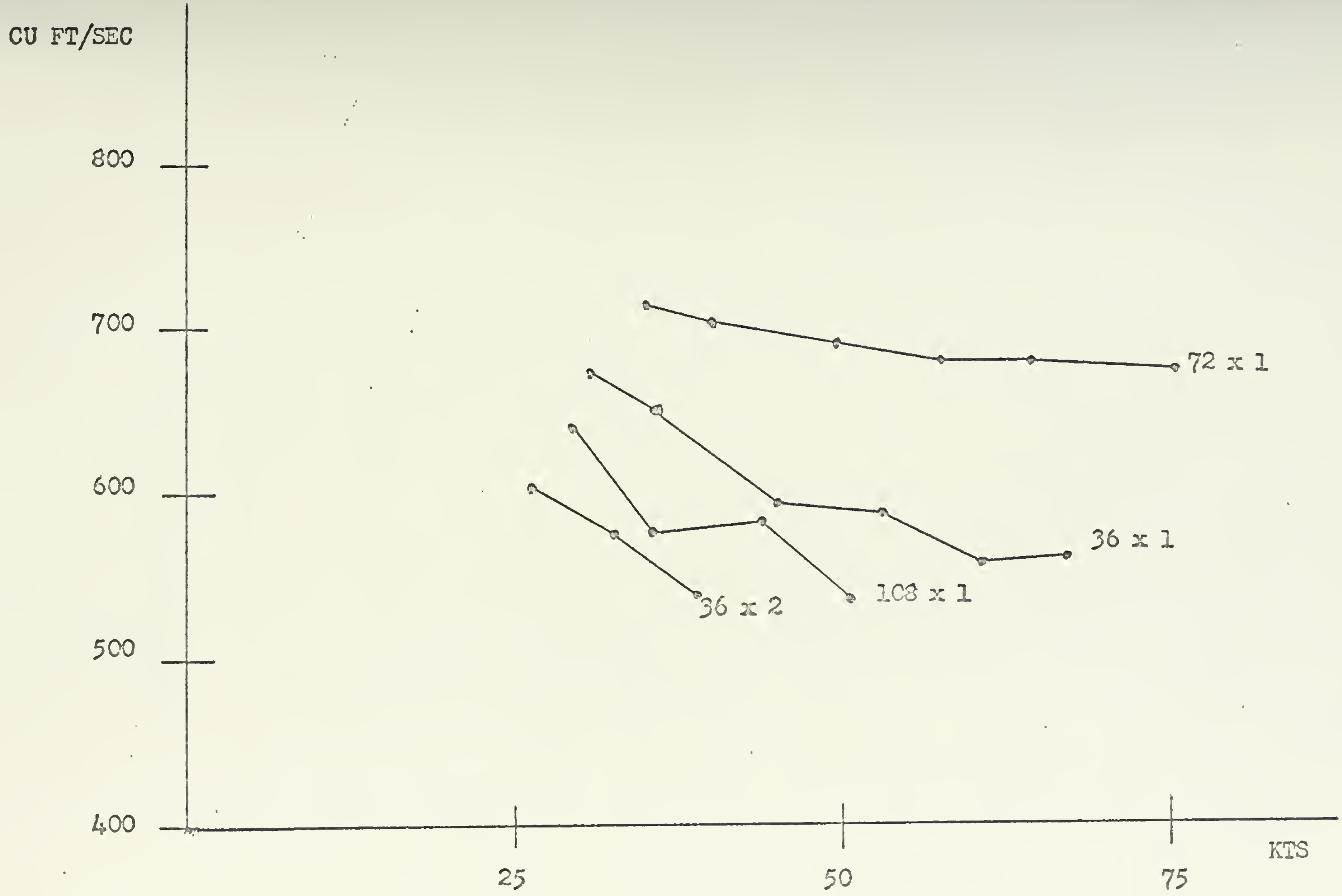


Figure 53. Average Bow Seal Input Fan Flow Rate Versus Steady-State Speed for Different Ahead Wave Conditions

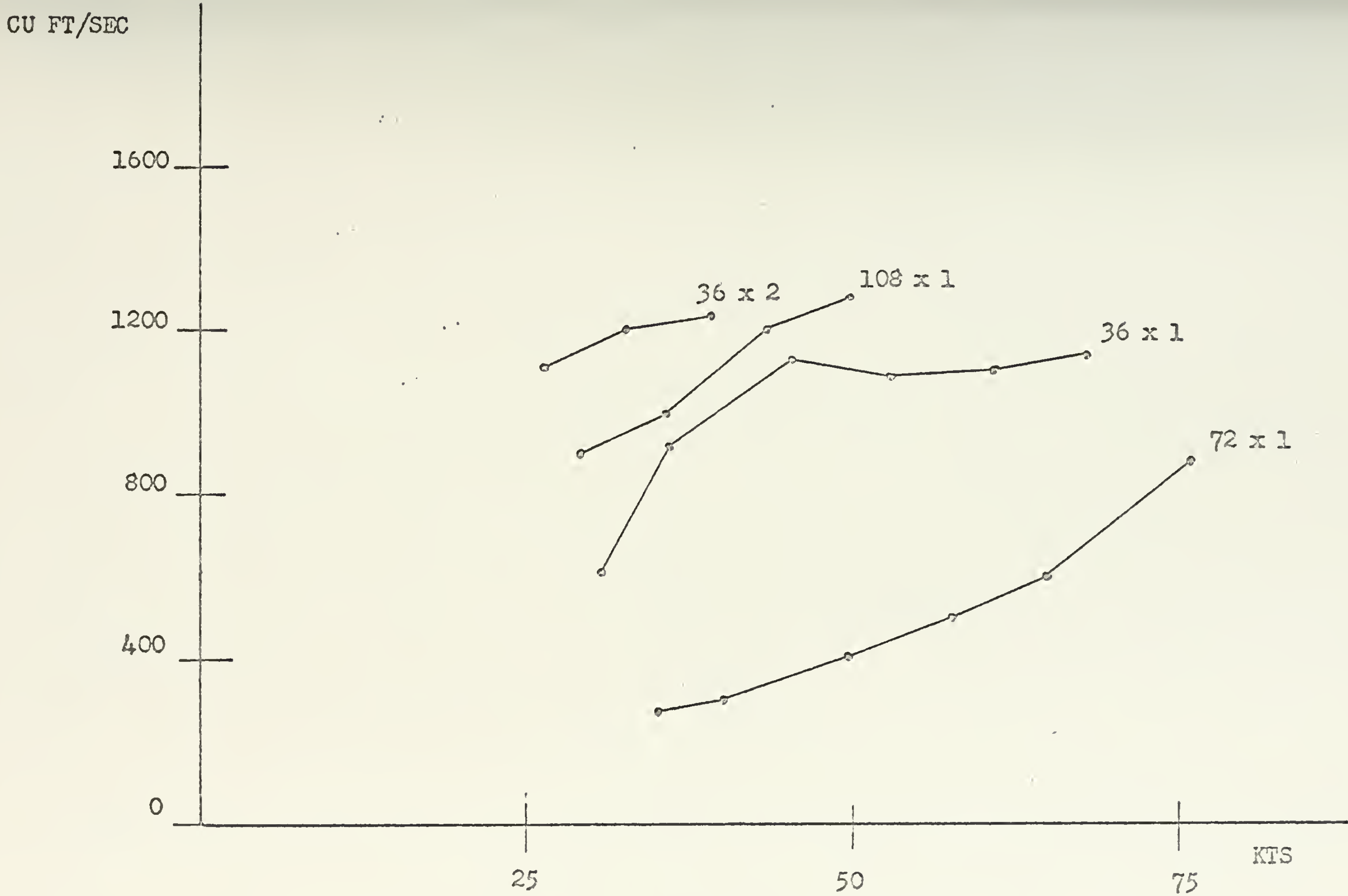


Figure 54. Fluctuation of Bow Seal Input Fan Flow Rate Versus Steady-State Speed for Different Ahead Wave Conditions

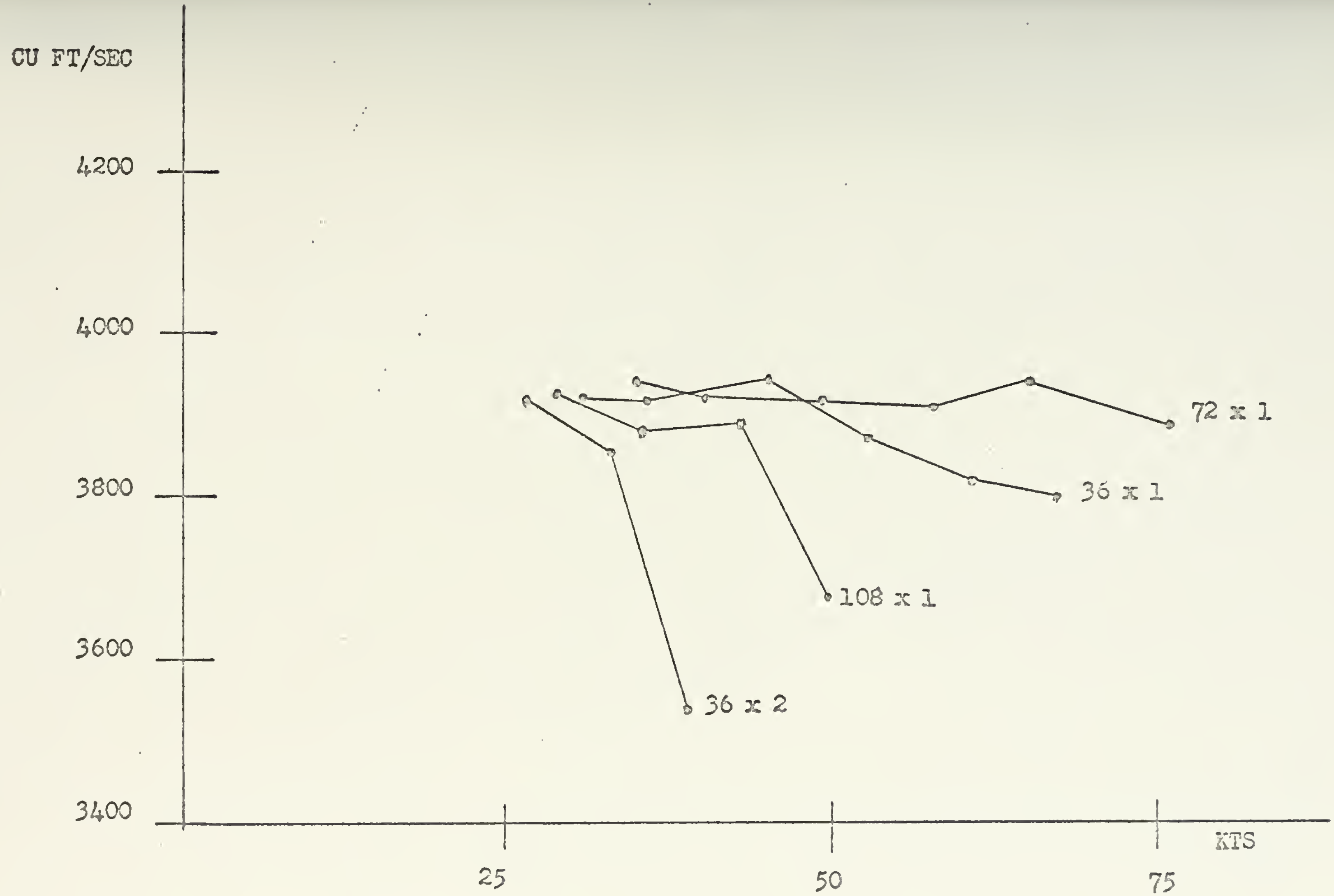


Figure 55. Average Plenum Input Fan Flow Rate Versus Steady-State Speed for Different Ahead Wave Conditions

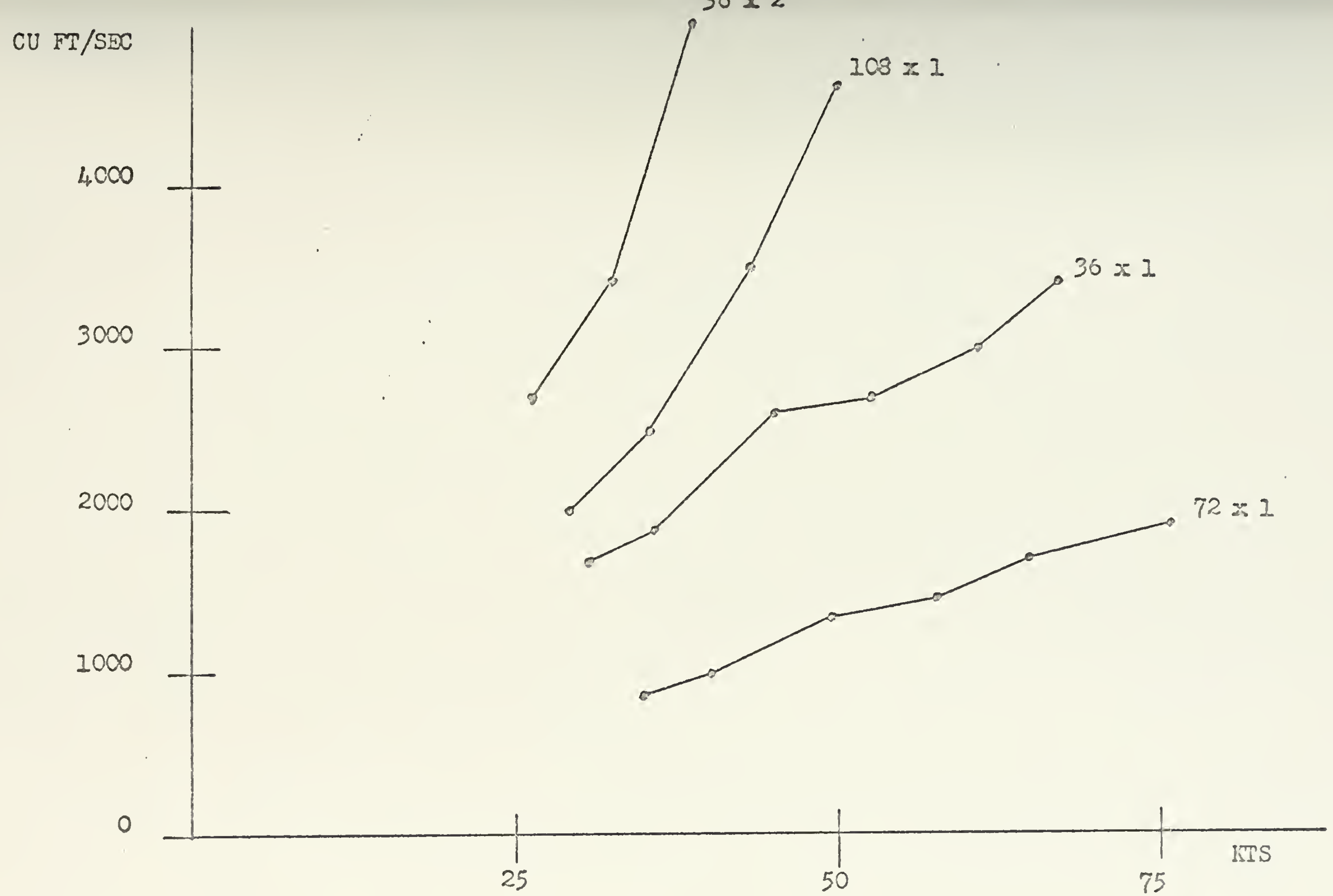


Figure 56. Fluctuation of Plenum Input Fan Flow Rate Versus Steady-State Speed for Different Ahead Wave Conditions

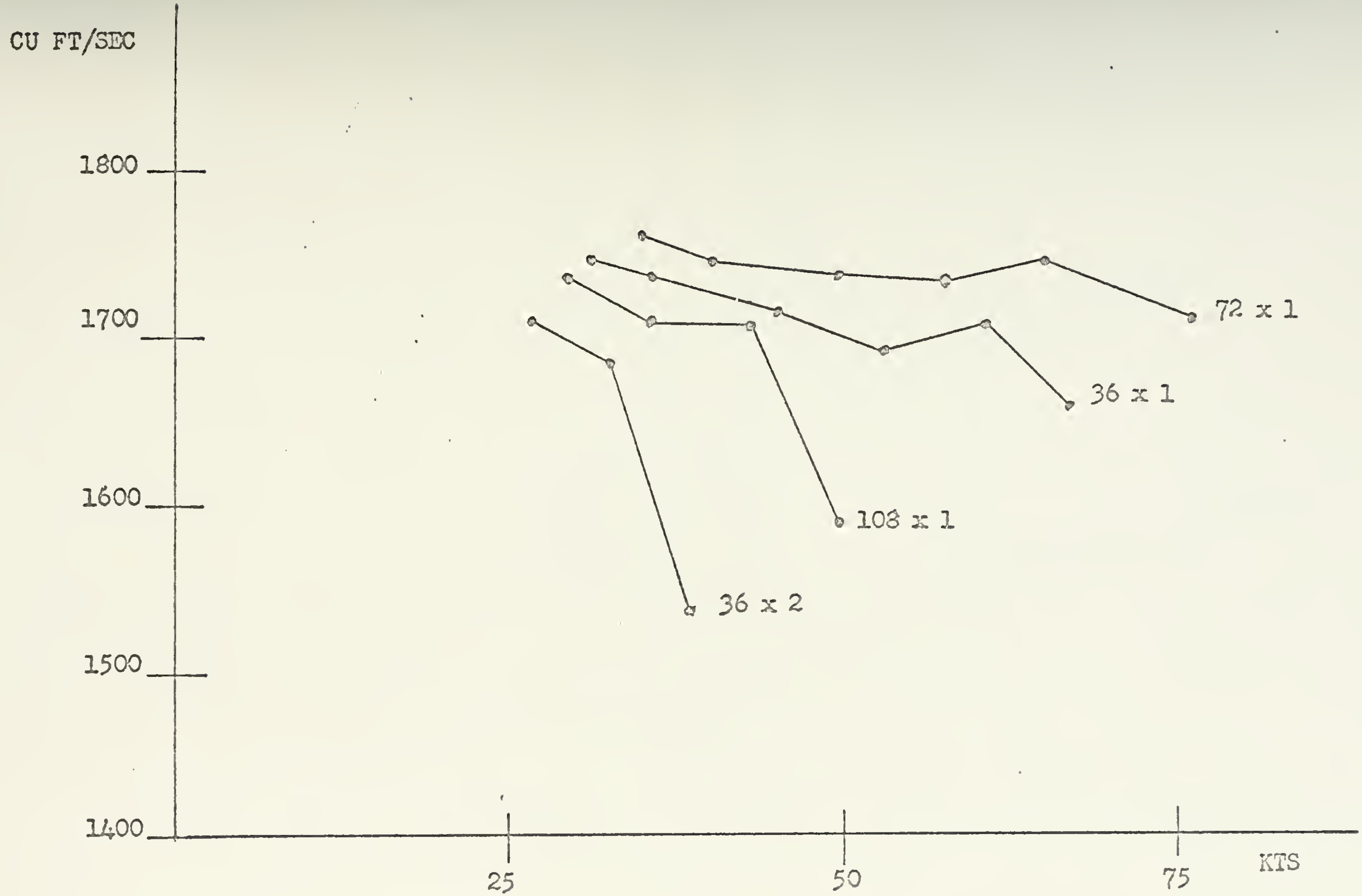


Figure 57. Average Stern Seal Input Fan Flow Rate Versus Steady-State Speed for Different Ahead Wave Conditions

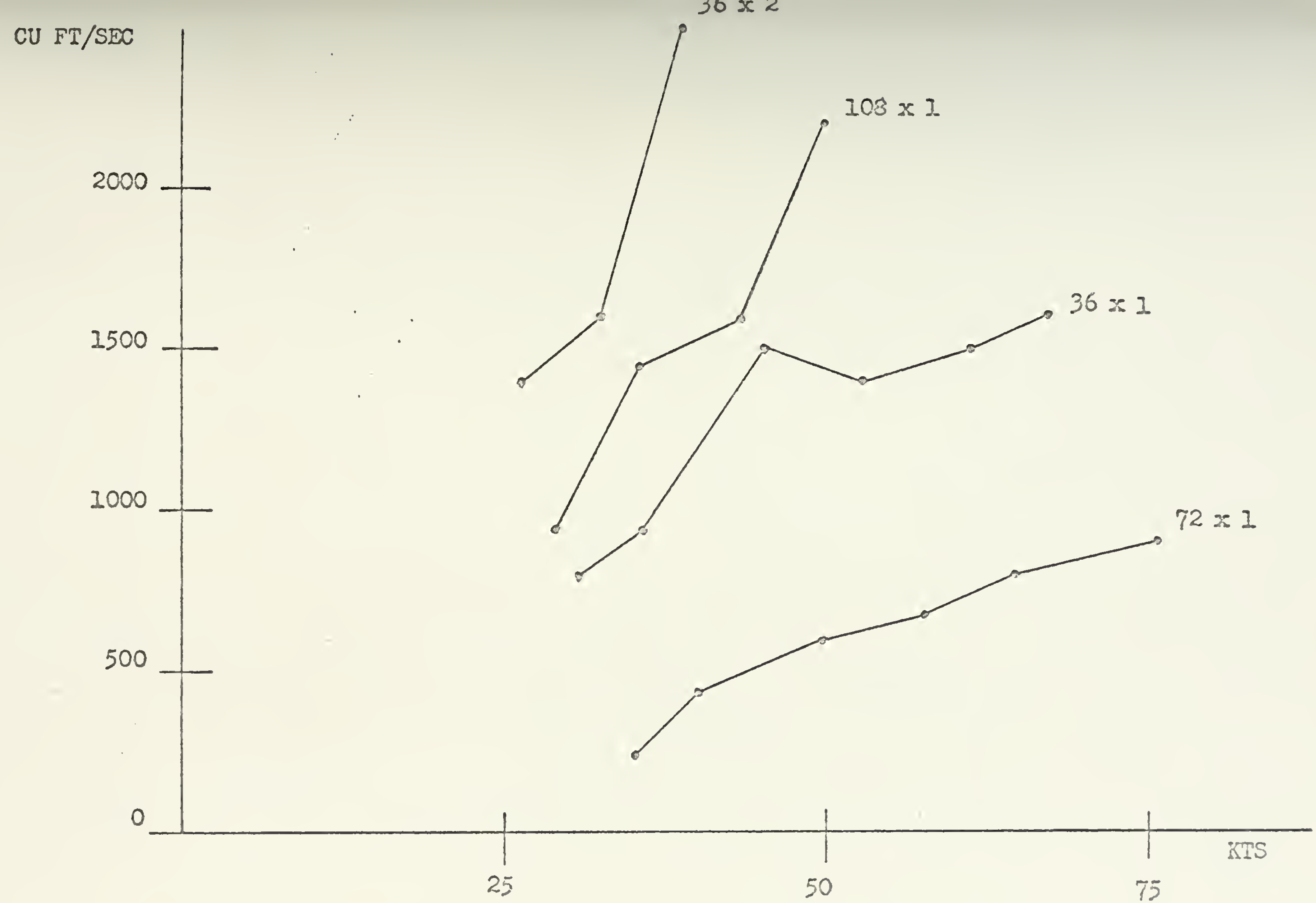


Figure 58. Fluctuation of Stern Seal Input Fan Flow Rate Versus Steady-State Speed for Different Ahead Wave Conditions

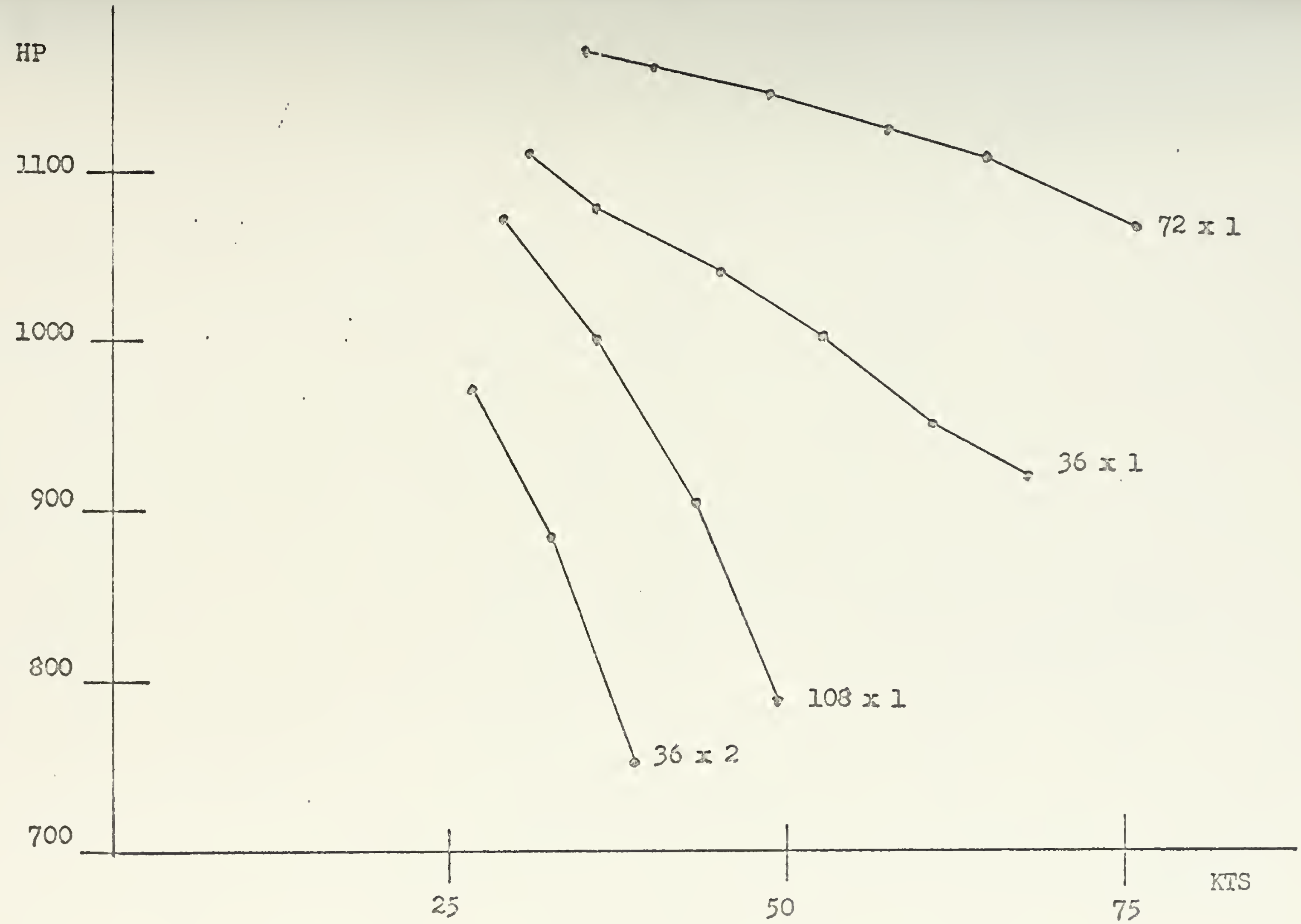


Figure 59. Average of Total Fan Power Versus Steady-State Speed for Different Ahead Wave Conditions

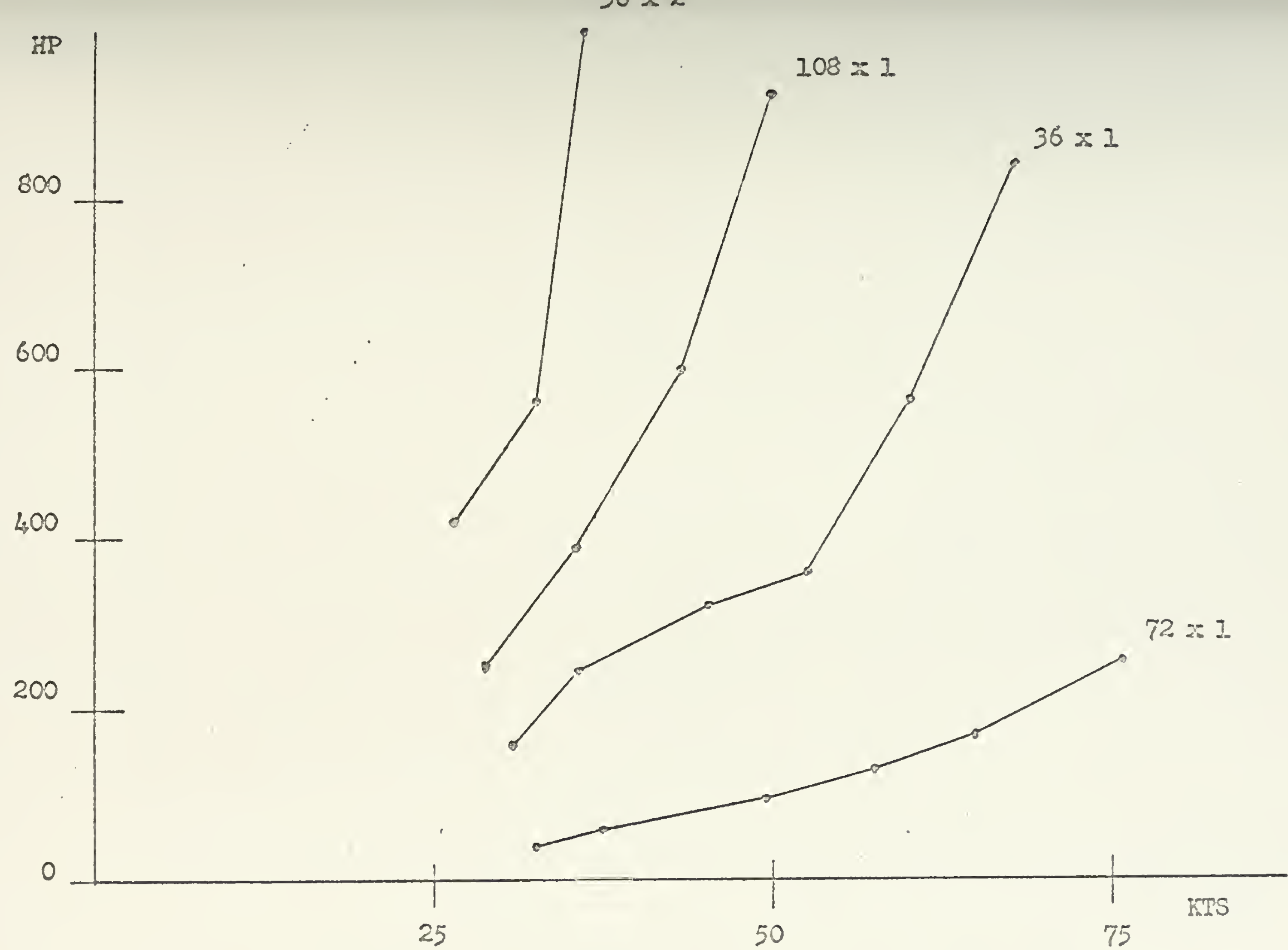


Figure 60. Fluctuation of Total Fan Power Versus Steady-State Speed for Different Ahead Wave Conditions

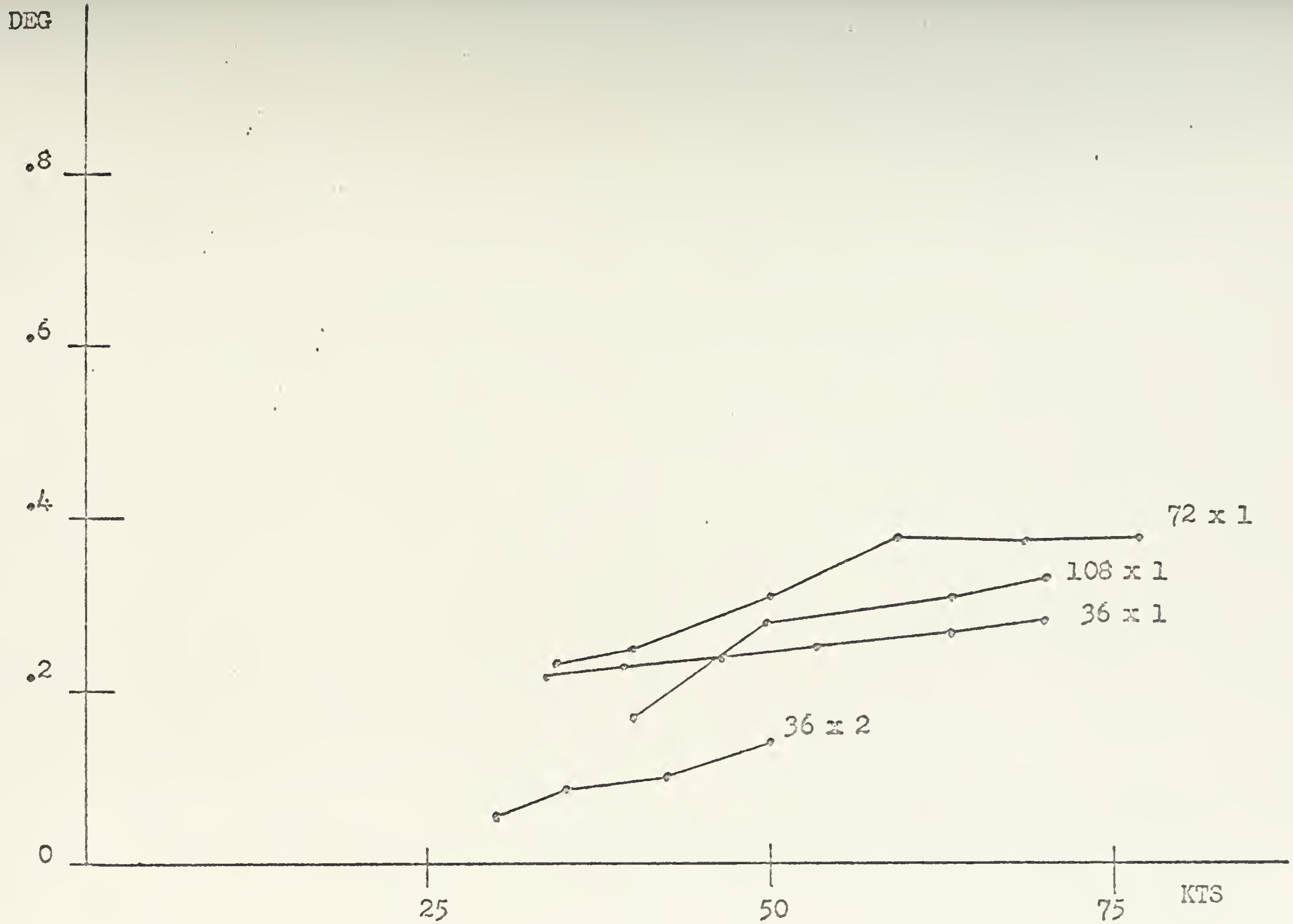


Figure 61. Average Pitch Angle Versus Steady-State Speed for Different Astern Wave Conditions

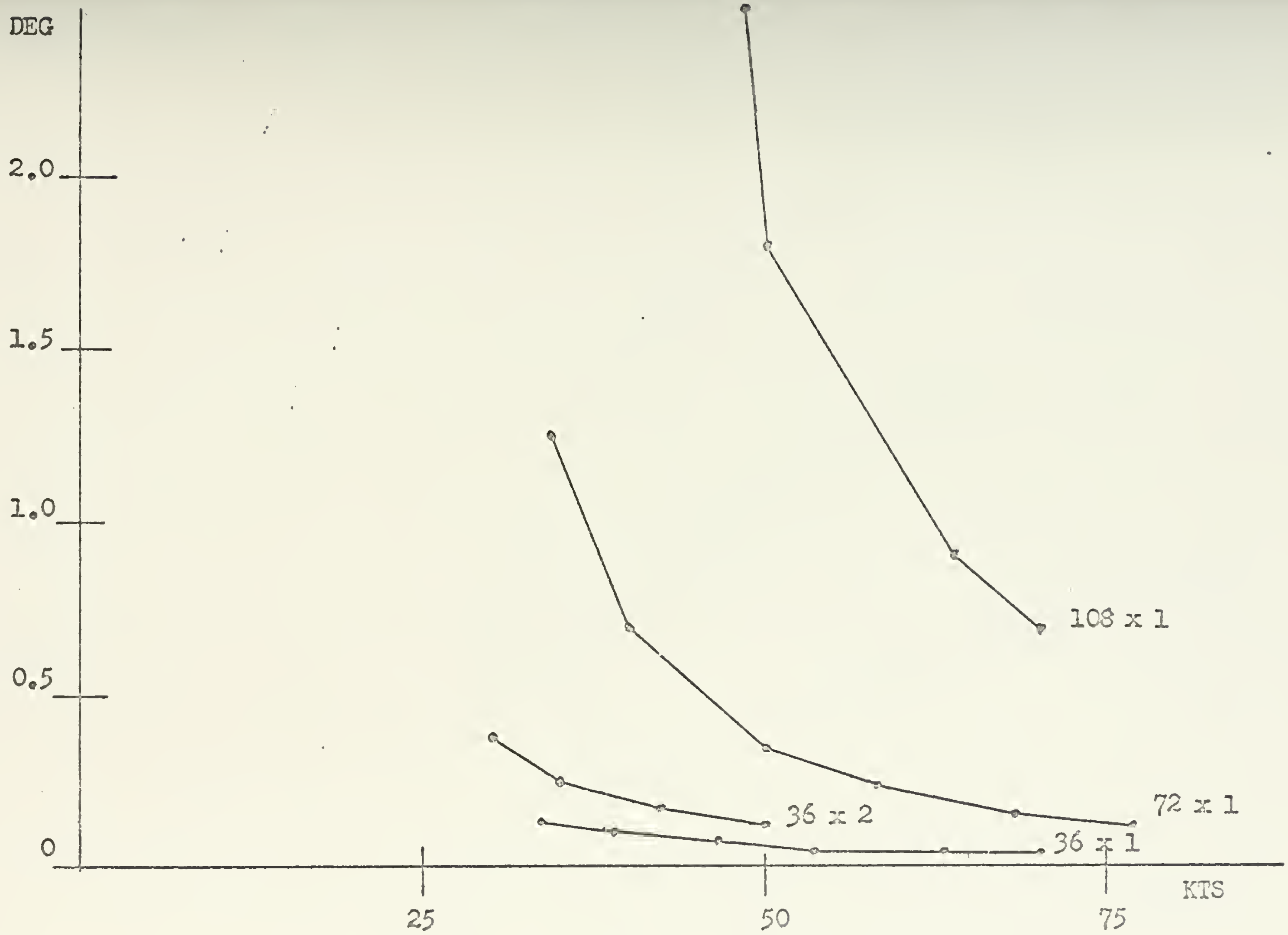


Figure 62. Fluctuation of Pitch Angle Versus Steady-State
Speed for Different Astern Wave Conditions

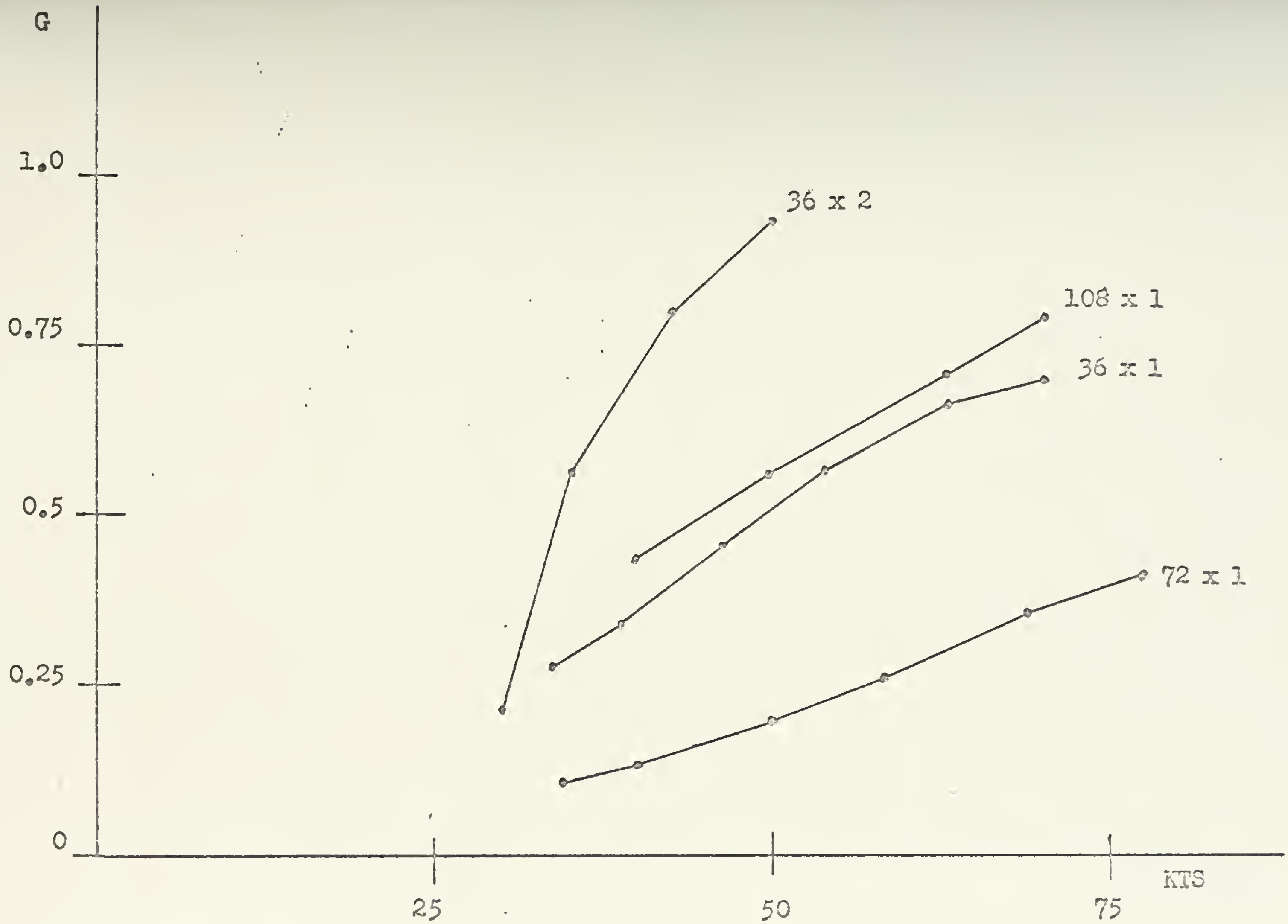


Figure 63. Fluctuation of Center of Gravity Acceleration Versus Steady-State Speed for Different Astern Wave Conditions

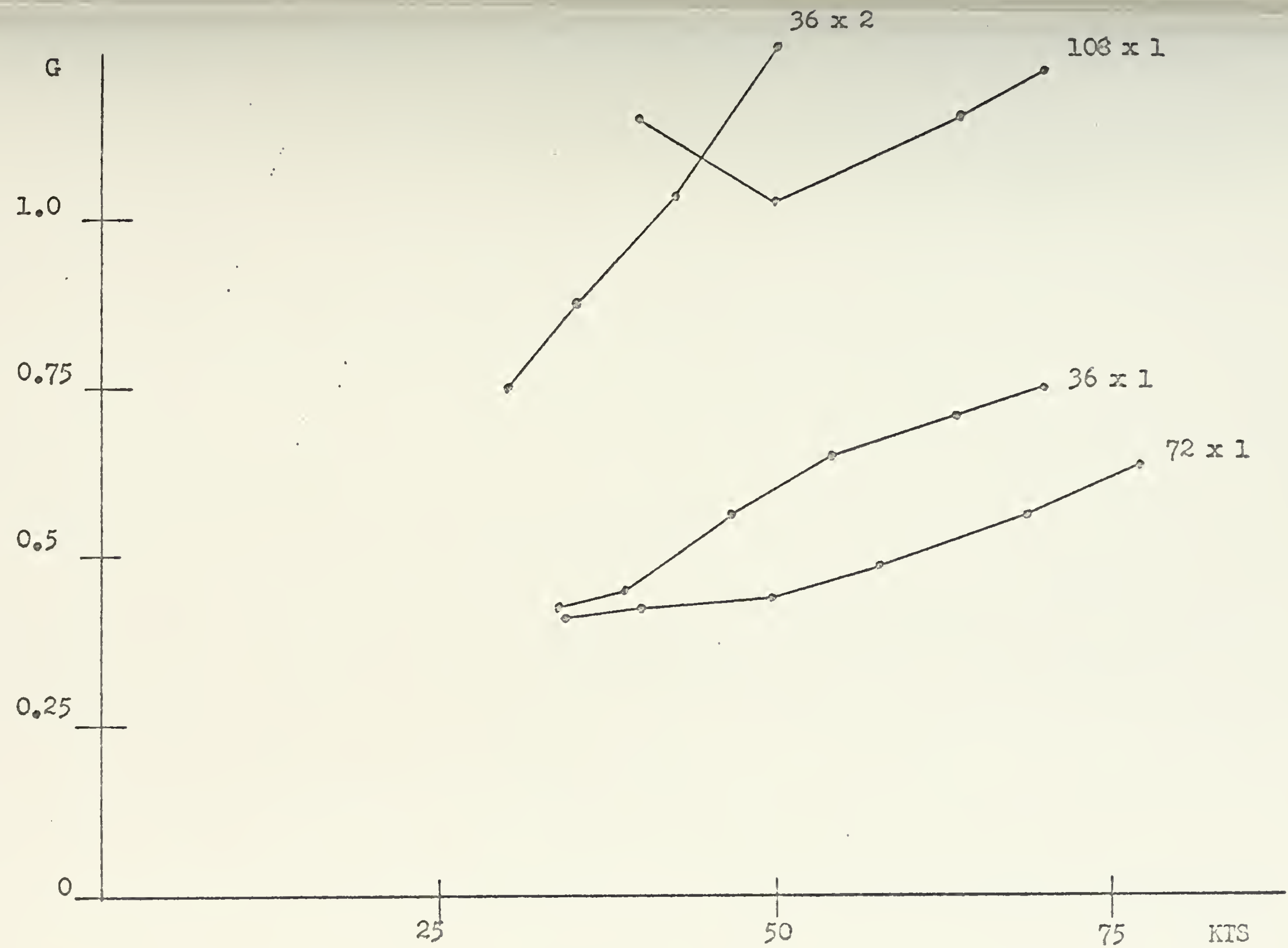


Figure 64. Fluctuation of Bow Acceleration Versus Steady-State Speed for Different Astern Wave Conditions

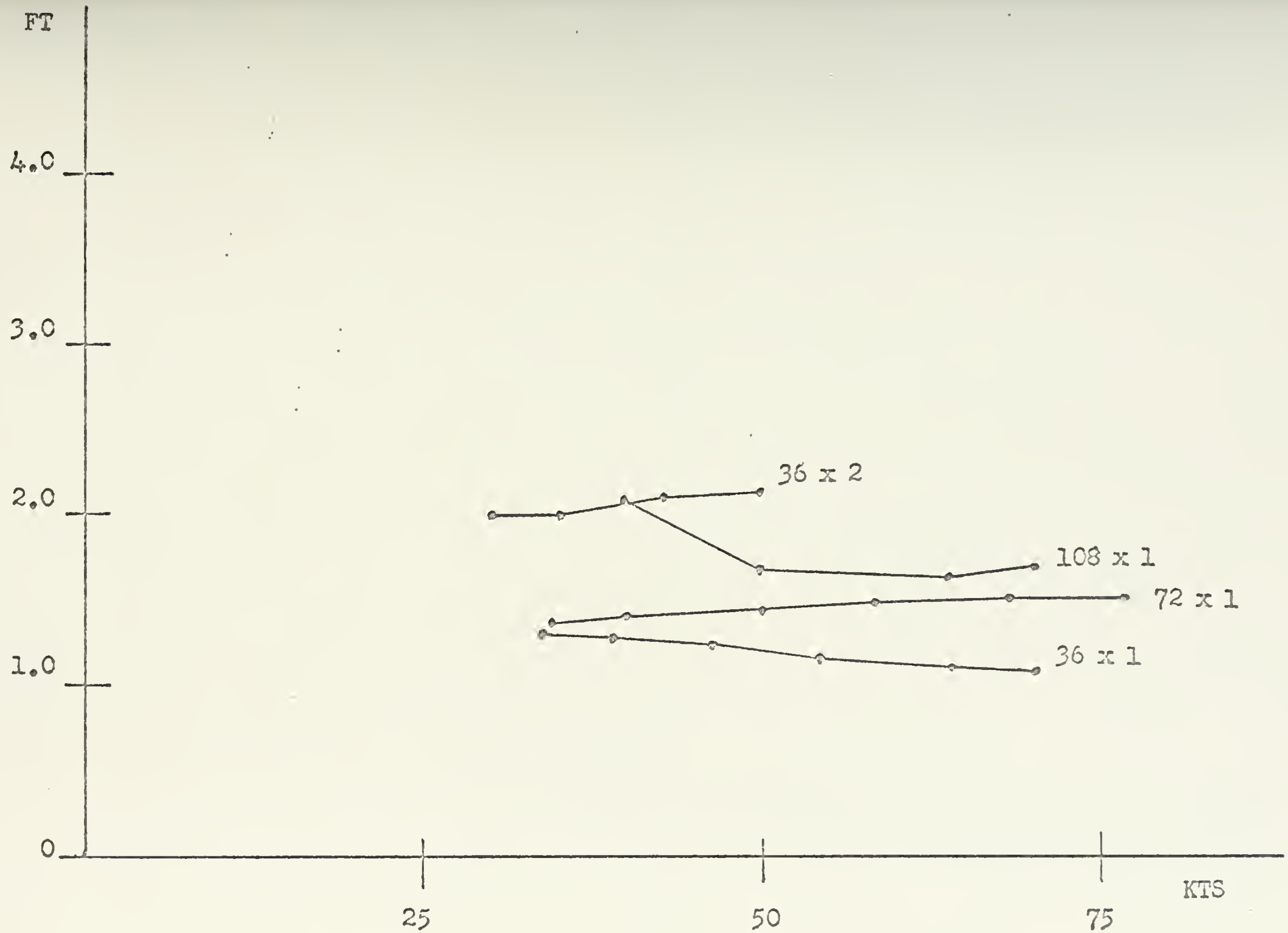


Figure 65. Average Draft Versus Steady-State Speed for Different Astern Wave Conditions

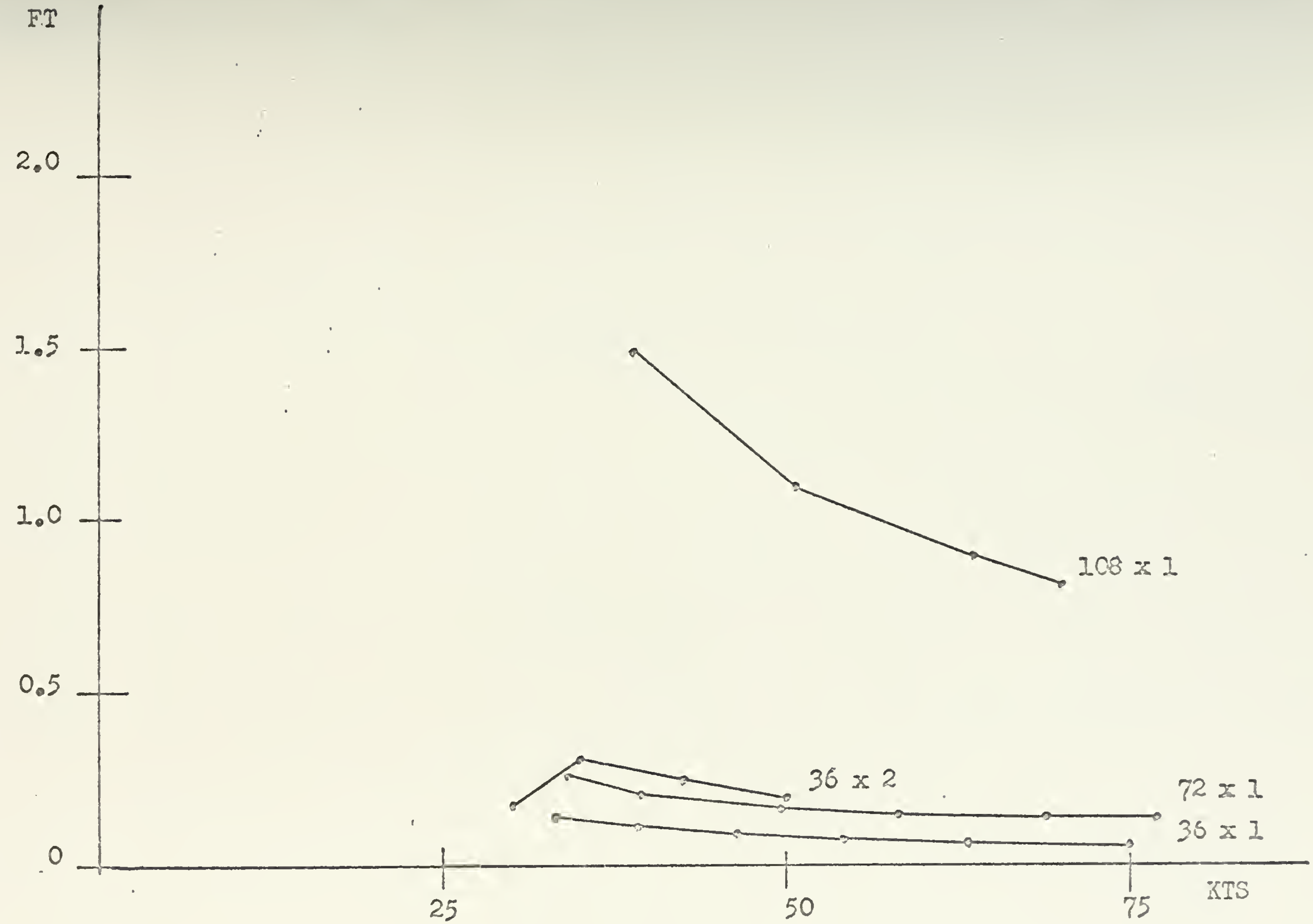


Figure 66. Fluctuation of Draft Versus Steady-State Speed for Different Astern Wave Conditions

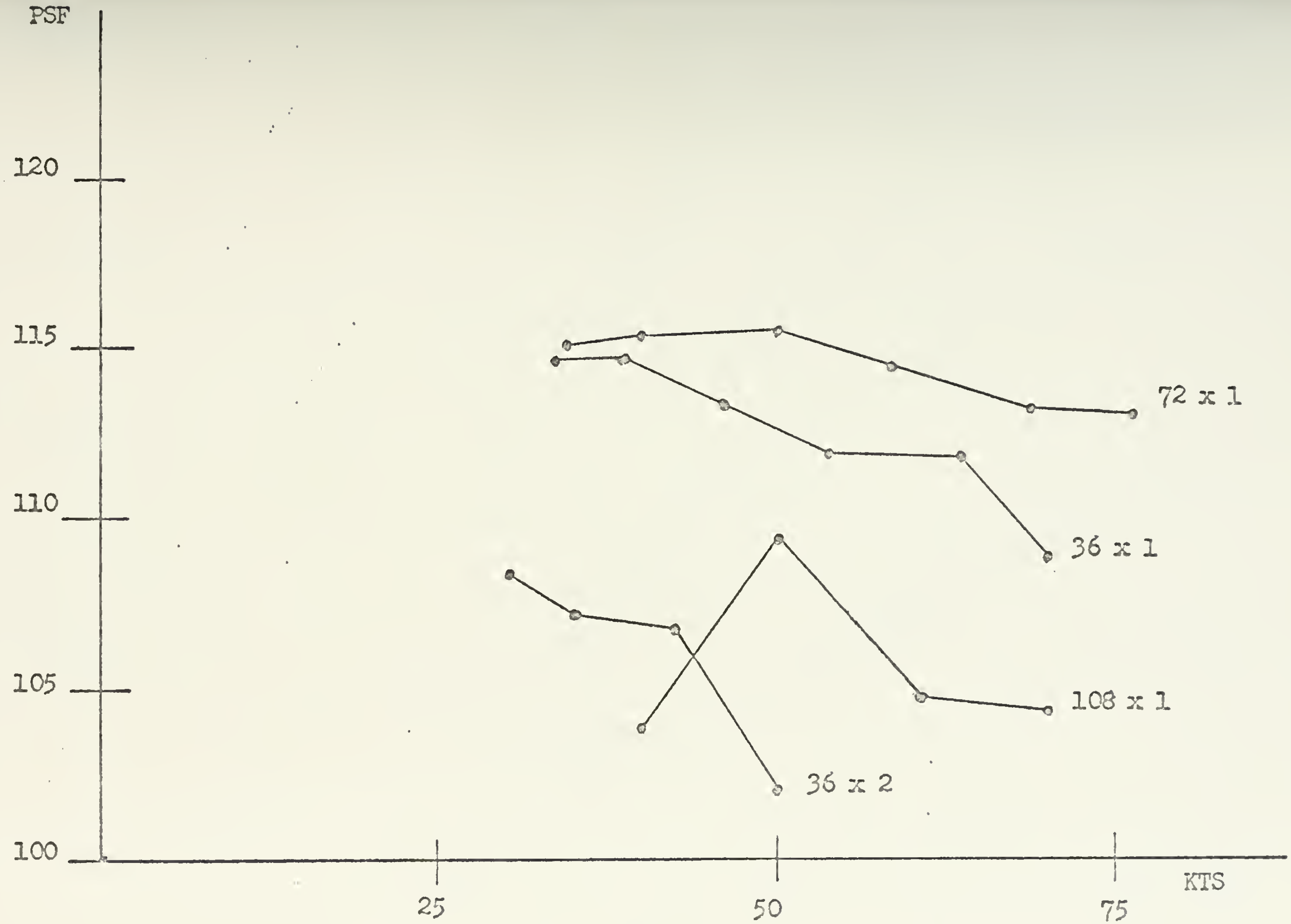


Figure 67. Average Bow Seal and Stern Seal Pressure Versus Steady-State Speed for Different Astern Wave Conditions

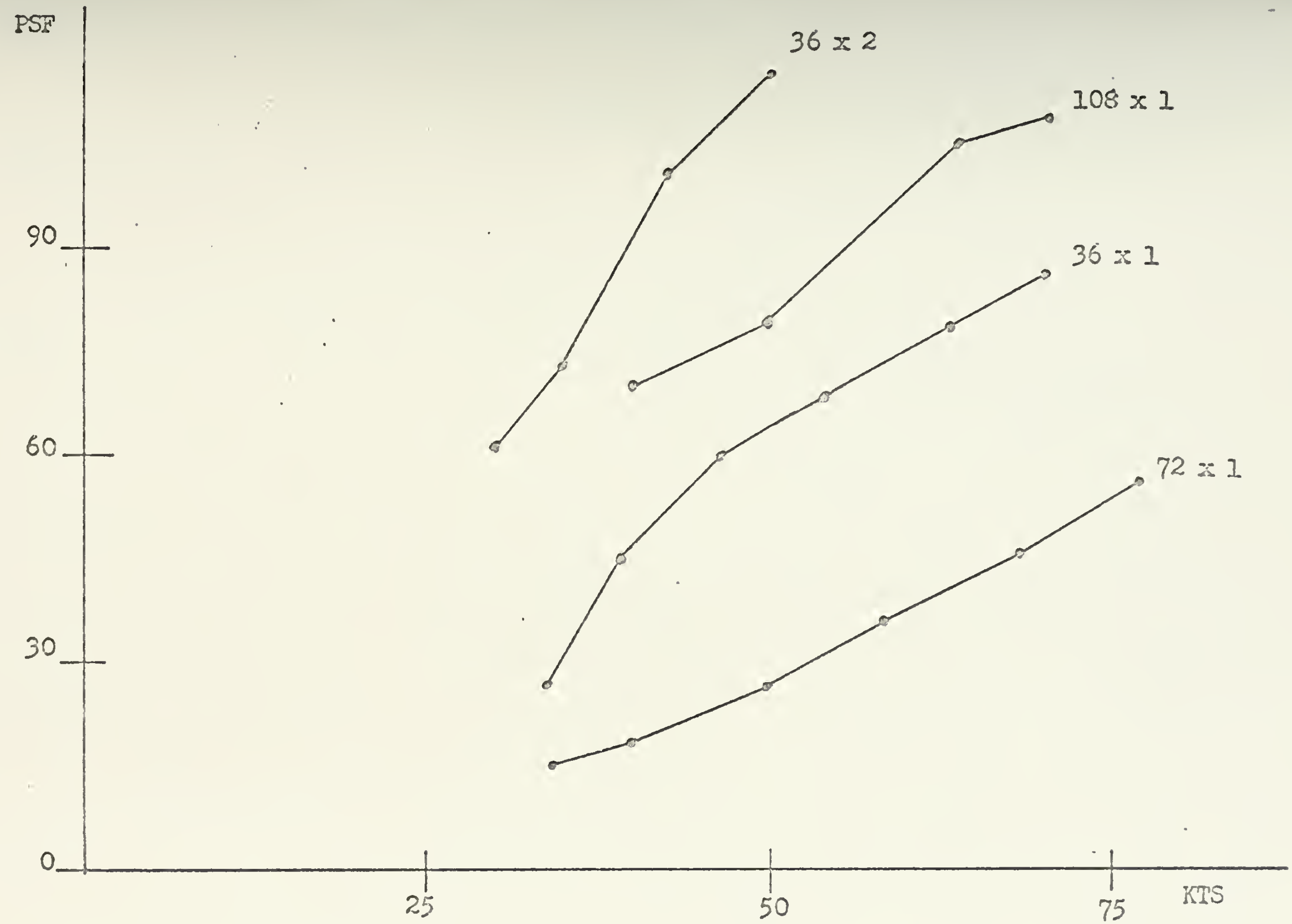


Figure 68. Fluctuation of Bow Seal and Stern Seal Pressure Versus Steady-State Speed for Different Astern Wave Conditions

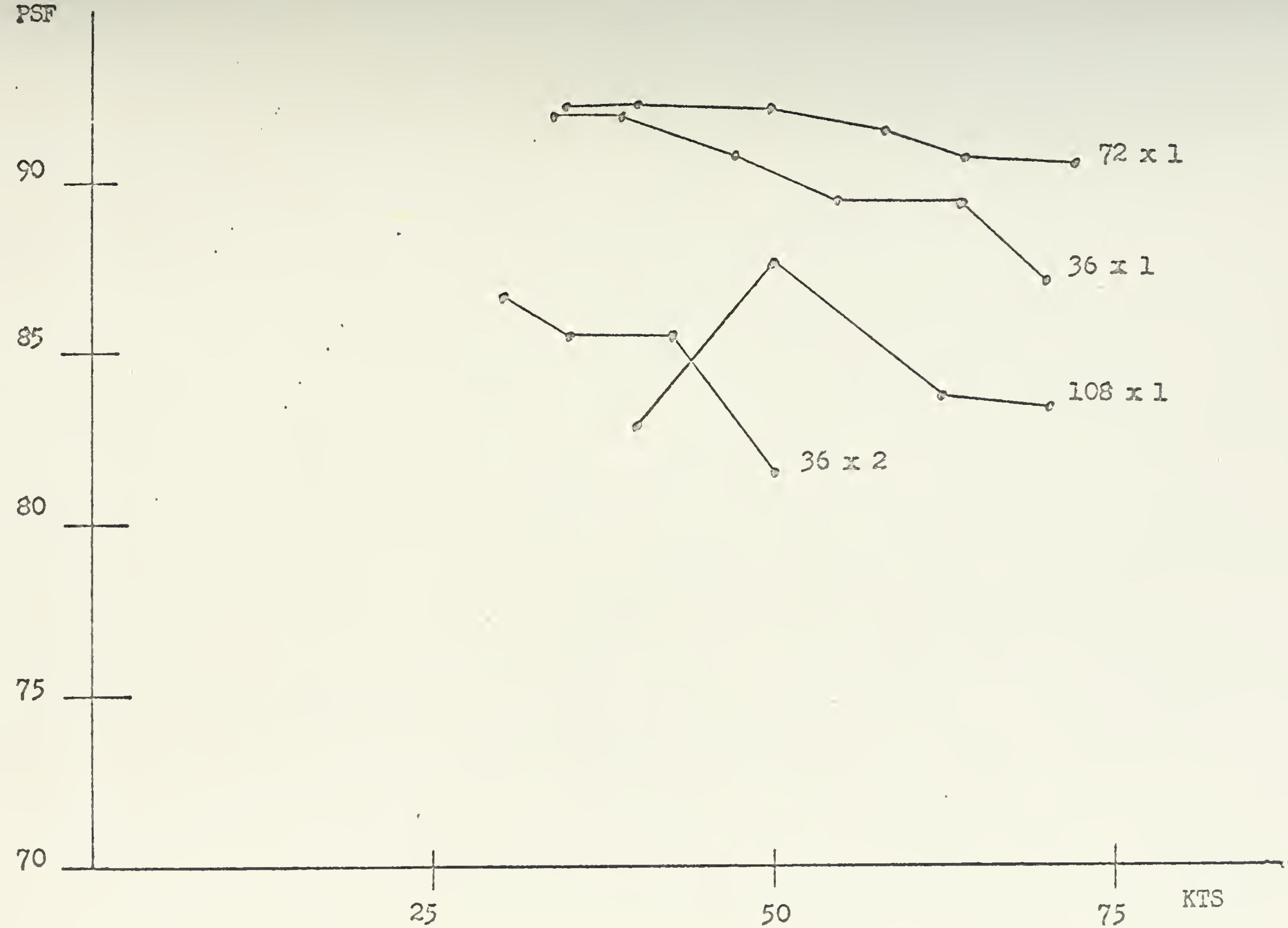


Figure 69. Average Plenum Pressure Versus Steady-State Speed for Different Astern Wave Conditions

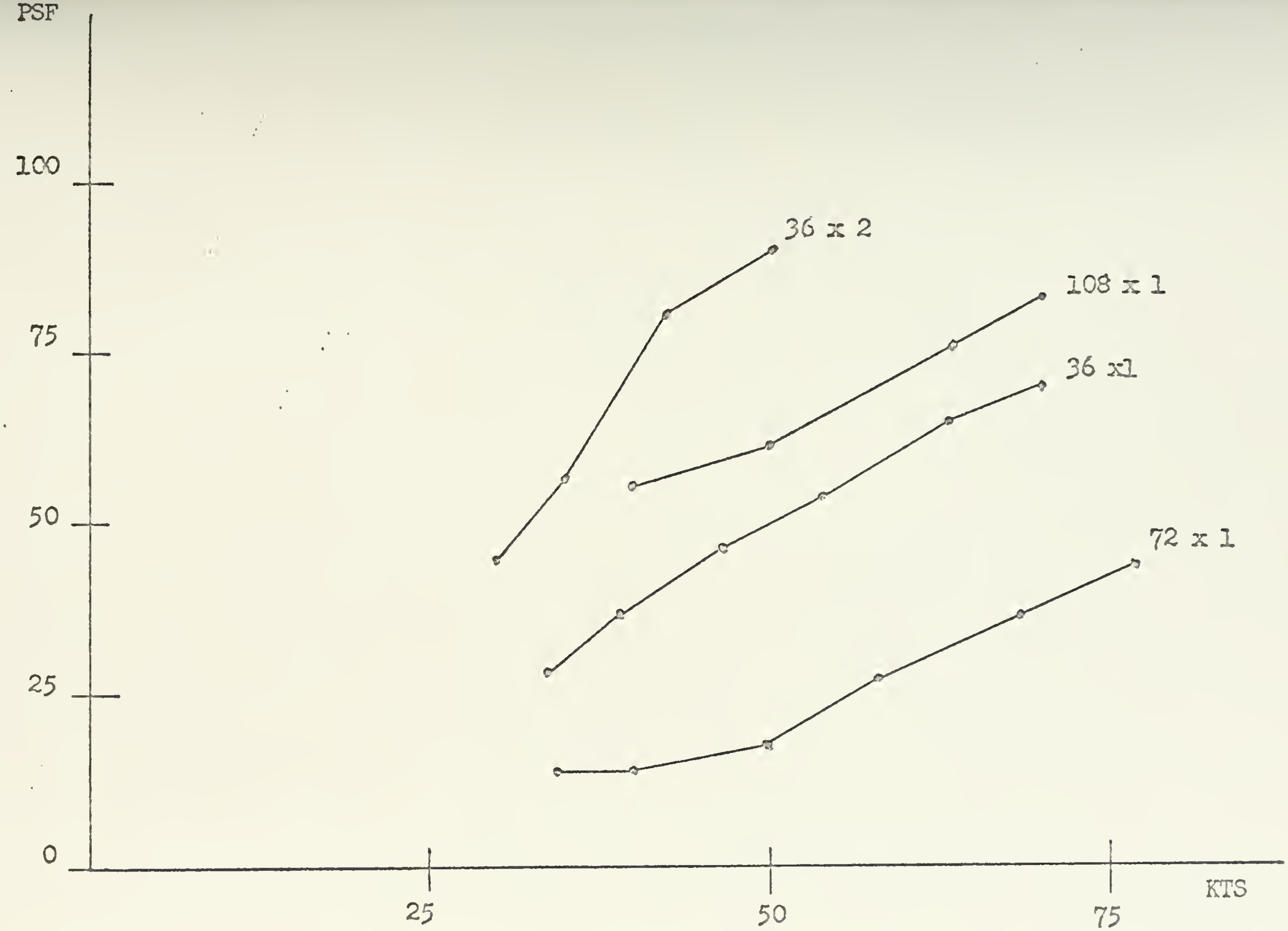


Figure 70. Fluctuation of Plenum Pressure Versus Steady-State Speed for Different Astern Wave Conditions

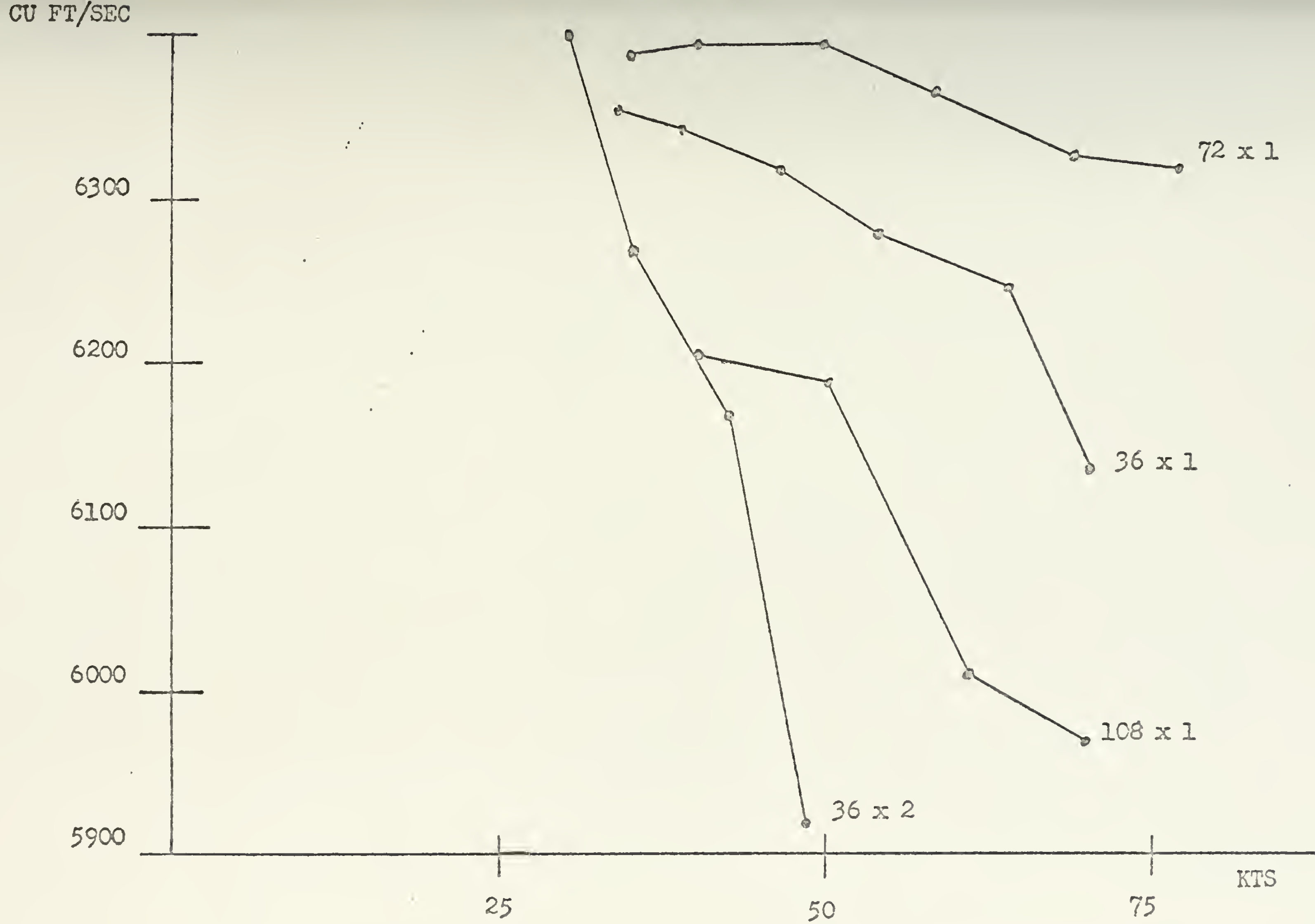


Figure 71. Average Stern Seal Leakage Rate Versus Steady-State Speed for Different Astern Wave Conditions

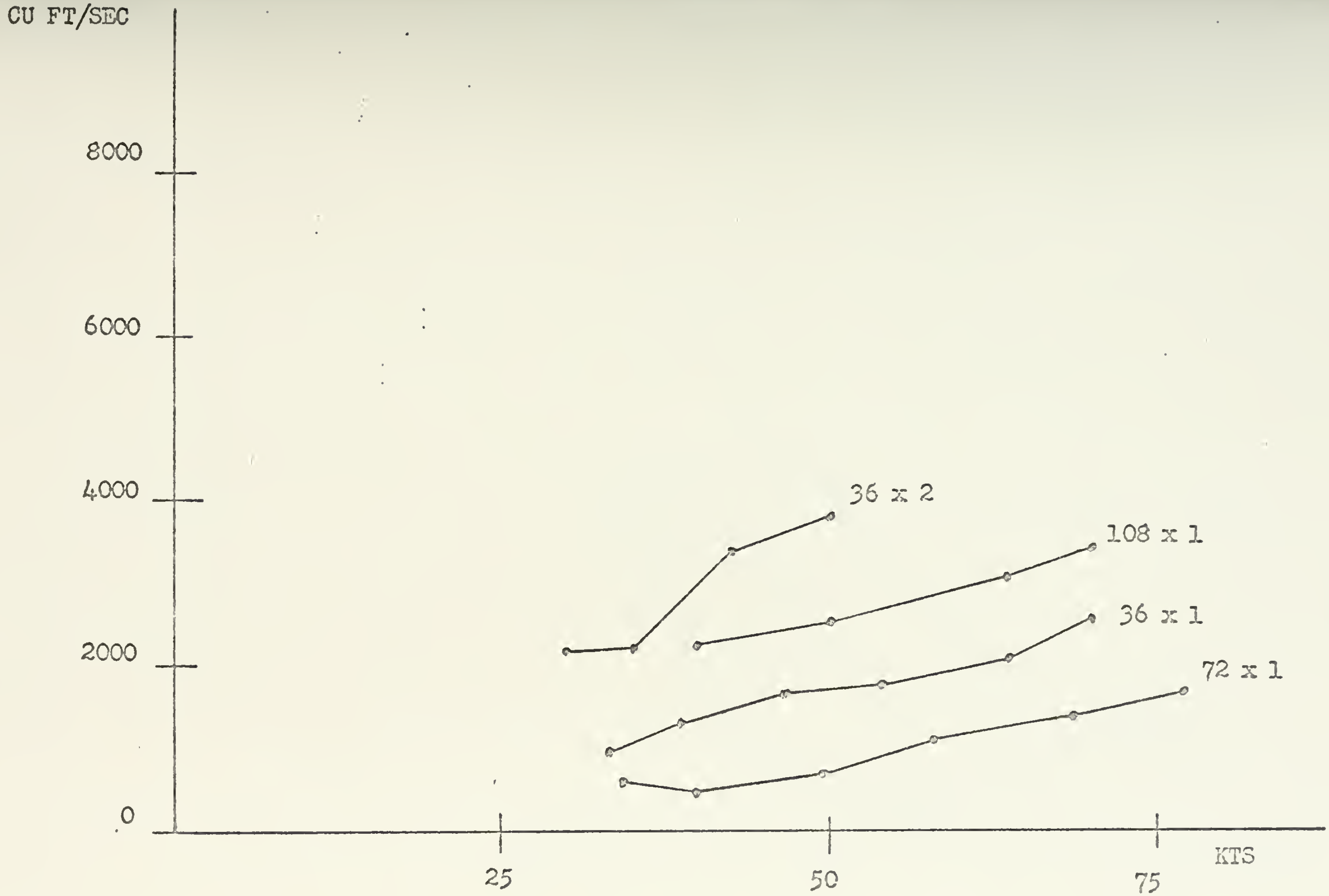


Figure 72. Fluctuation of Stern Seal Leakage Rate Versus Steady-State Speed for Different Astern Wave Conditions

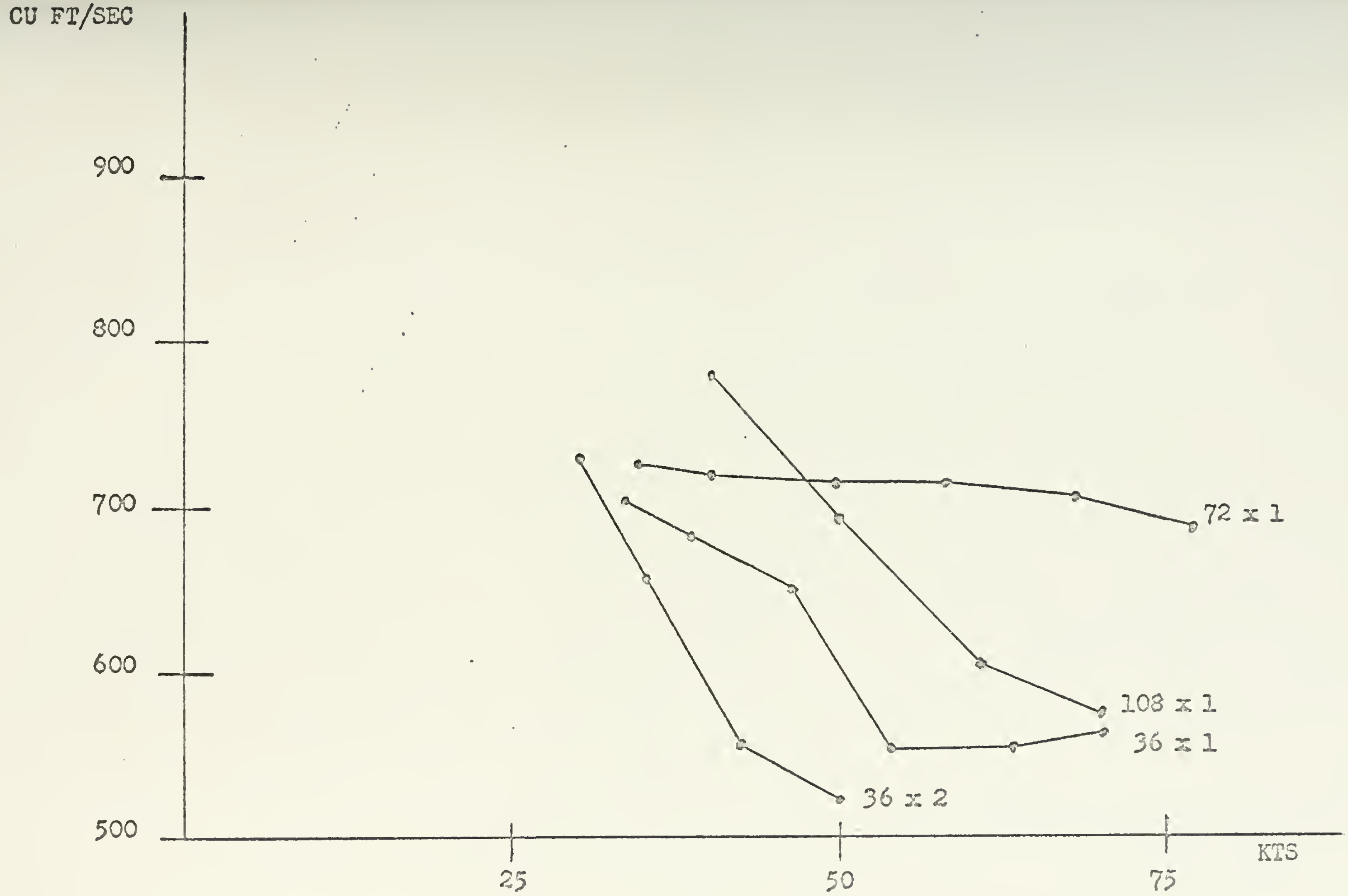


Figure 73. Average Bow Seal Input Fan Flow Rate Versus Steady-State Speed for Different Astern Wave Conditions

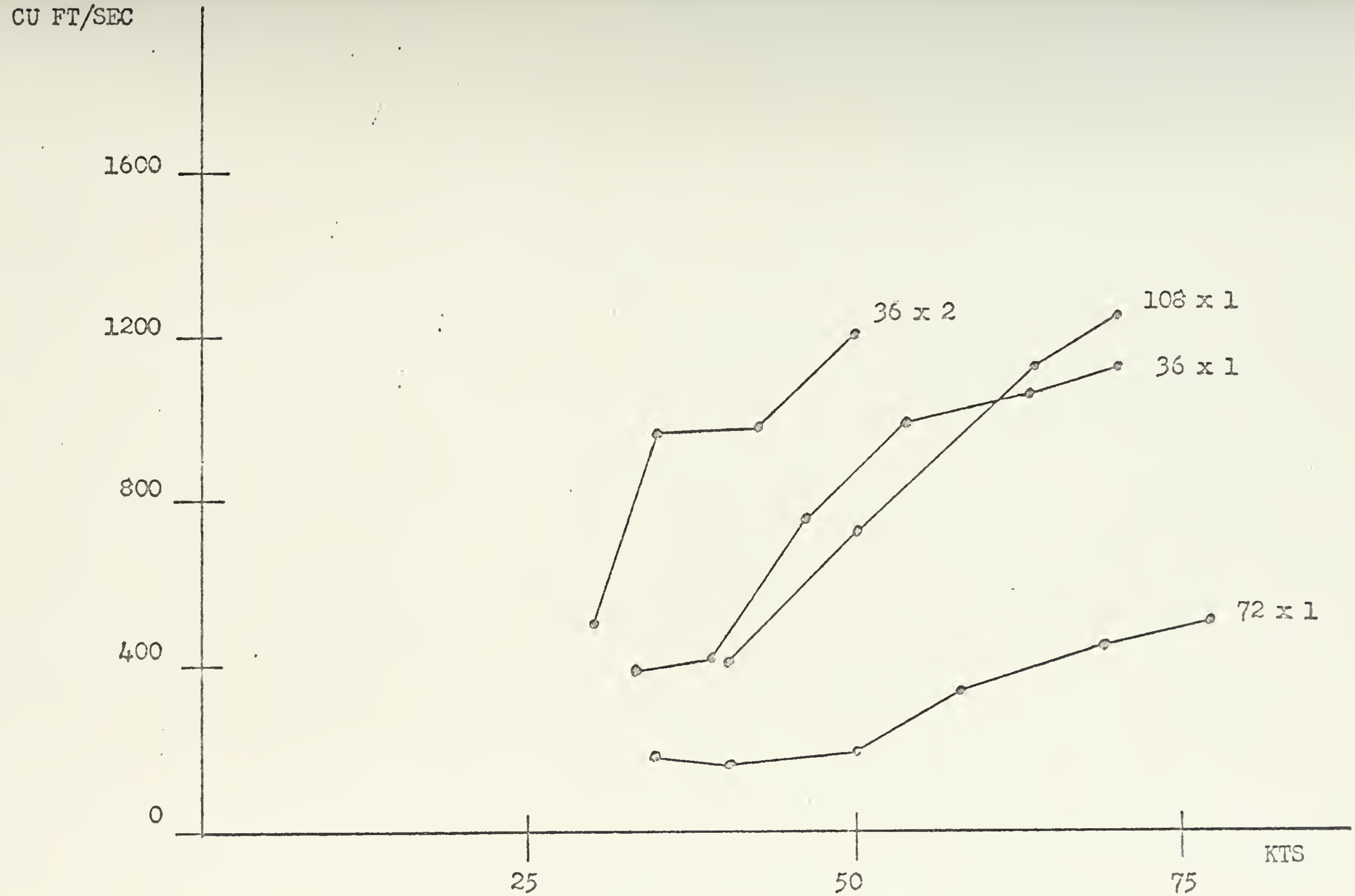


Figure 74. Fluctuation of Bow Seal Input Fan Flow Rate Versus Steady-State Speed for Different Astern Wave Conditions

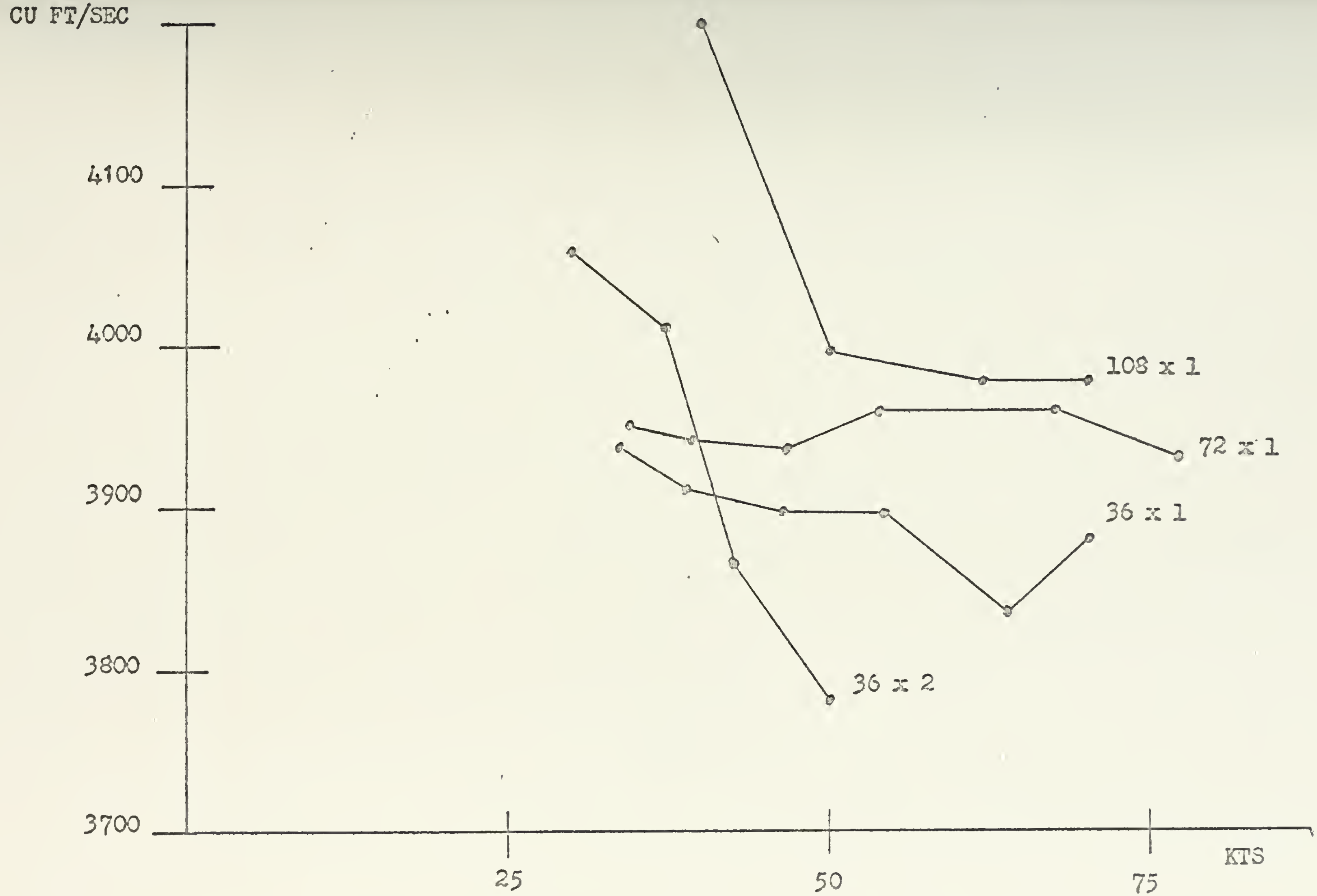


Figure 75. Average Plenum Input Fan Flow Rate Versus Steady-State Speed for Different Astern Wave Conditions

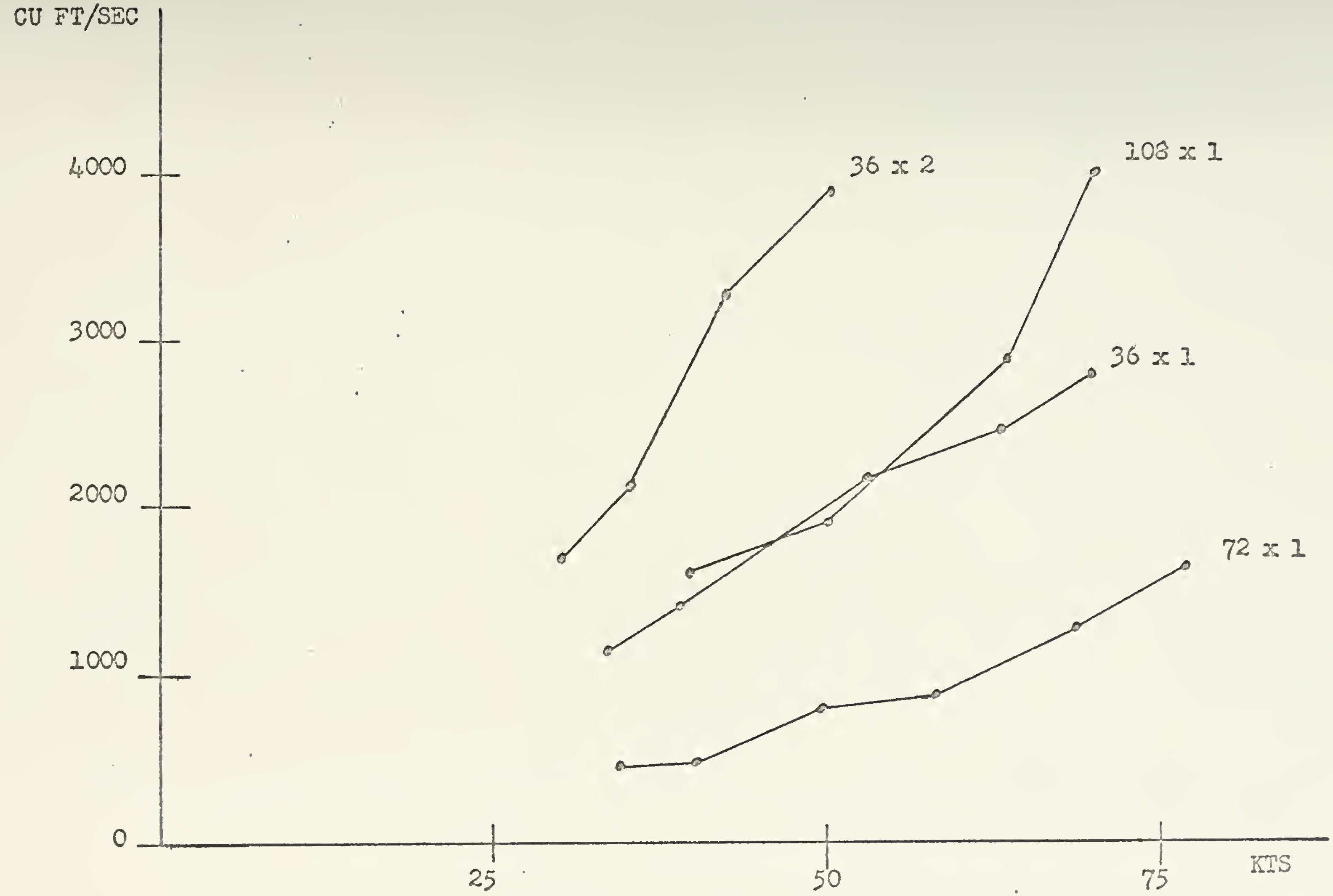


Figure 76. Fluctuation of Plenum Input Fan Flow Rate Versus Steady-State Speed for Different Astern Wave Conditions

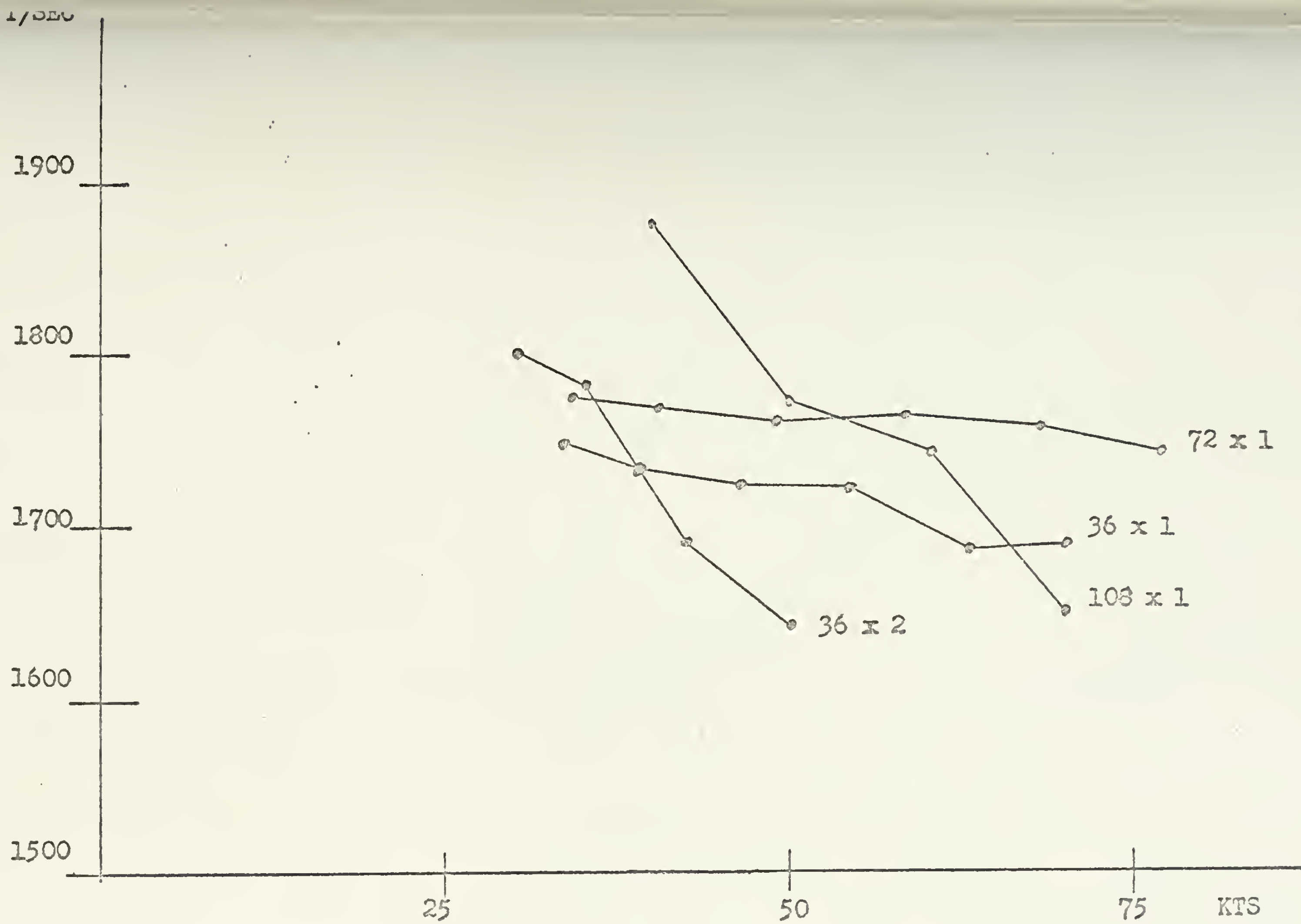


Figure 77. Average Stern Seal Input Fan Flow Rate Versus Steady-State Speed for Different Astern Wave Conditions

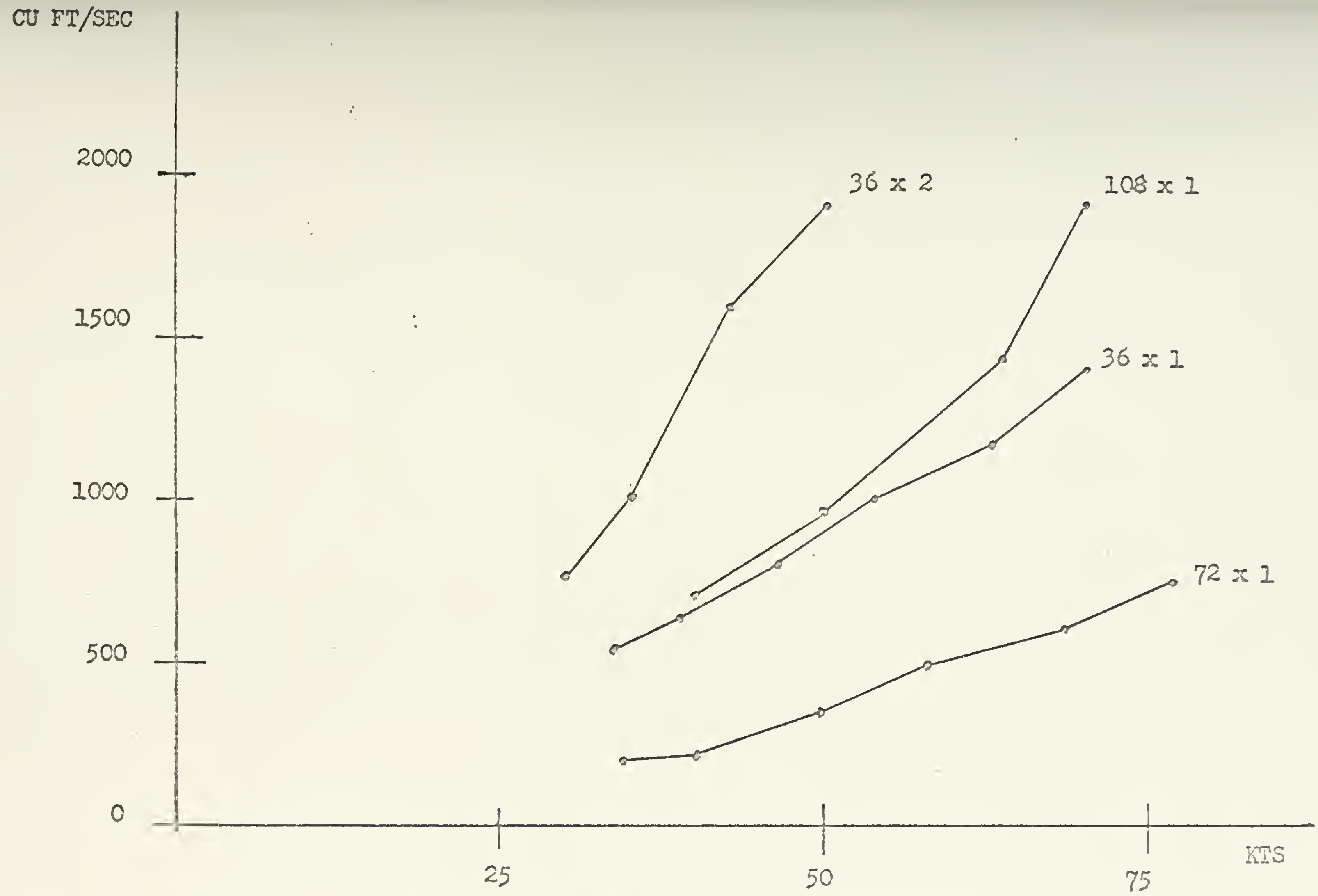


Figure 78. Fluctuation of Stern Seal Input Fan Flow Rate Versus Steady-State Speed for Different Astern Wave Conditions

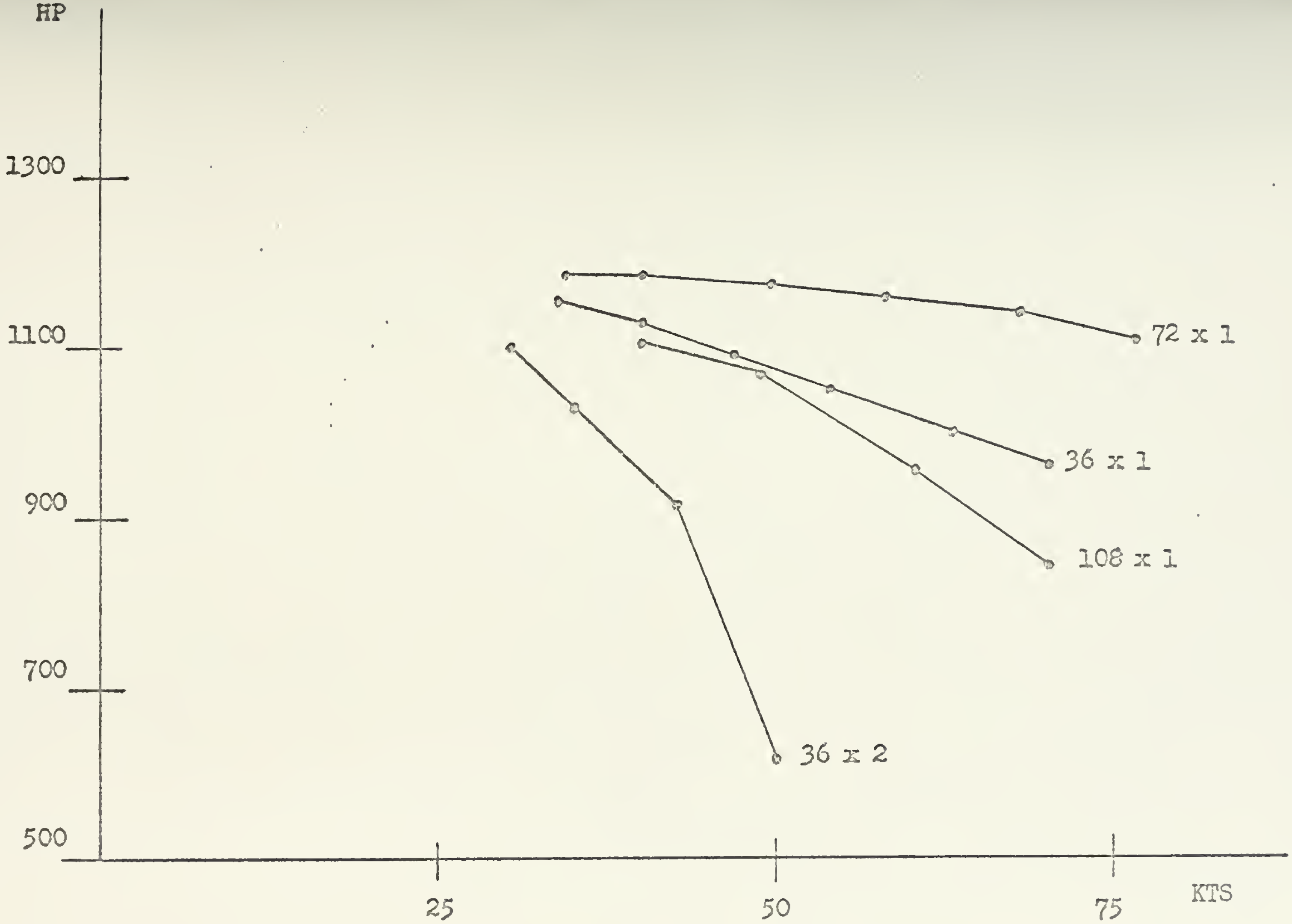


Figure 79. Average of Total Fan Power Versus Steady-State Speed for Different Astern Wave Conditions

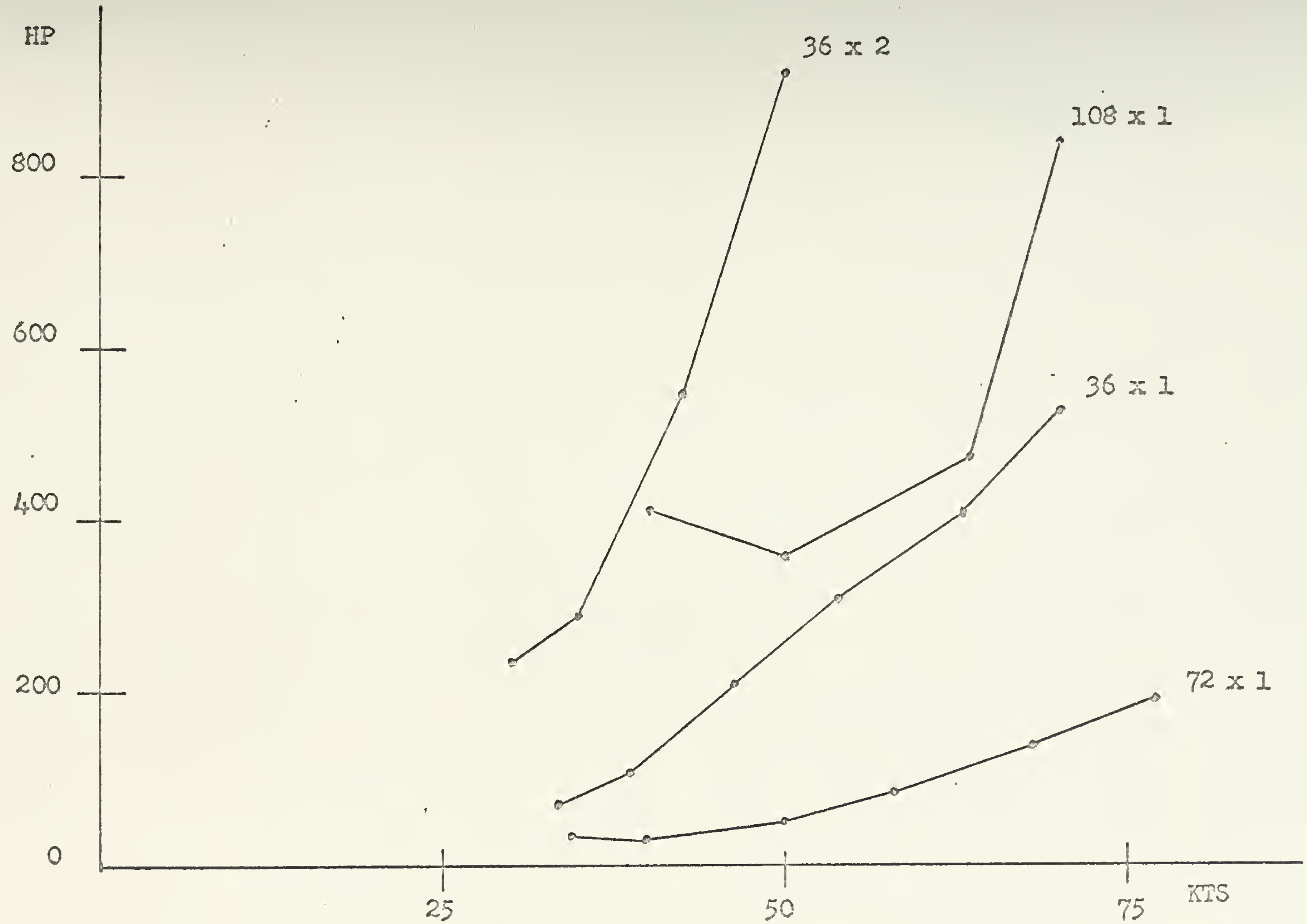


Figure 80. Fluctuation of Total Fan Power Versus Steady-State Speed for Different Astern Wave Conditions

V. DISCUSSION

A. CAPTURE AIR BUBBLE CONCEPT

The Capture Air Bubble (CAB) ship is designed to run along the water surface on a cushion (bubble) of air. The concept is to "capture" the air supplied by fans in the plenum by using rigid sidewalls and flexible bow and stern seals. The air that is captured in the plenum area will reduce the draft of the craft and in turn will reduce the amount of drag. This allows a higher speed at a given amount of thrust for the CAB ship than a conventional monohull craft of the same gross weight.

In the computer simulation of the 100-B SES, an initial base leakage of 6417 cubic feet per second was assumed to occur out the stern seal under calm water conditions at a plenum pressure of 92.8 PSF. The plenum volume, under calm water conditions, varied between 9,200 and 10,200 cubic feet. The variation in plenum volume is due to the speed of the craft. At slower speeds the draft was greater causing a decrease in plenum volume.

No matter what the speed of the craft is, the calm water results indicated that the volume of the plenum was replenished approximately every 1.5 to 2.0 seconds. A leakage of 6417 cubic feet per second may not be considered as extremely excessive, but the fact that the plenum is replenished every 1.5 to 2.0 seconds appears to be in contradiction to the theory of the "captured" air bubble.

Figures 51 and 71 show that increasing speed and increasing the wave amplitude will reduce the average rate of stern seal leakage. The average plenum pressures and the bow and stern seal pressures also decrease with an increase in speed and wave amplitude as shown in Figs. 47, 49, 67, and 69. This agrees with the computer program since leakage rate is dependent upon the area of the gap created and the associated pressures. However, the average input of air into the bow seal, stern seal, and plenum also decreases with an increase in speed and wave amplitude as shown in Figs. 53, 55, 57, 73, 75, and 77. This is contrary to the computer program where a decrease in pressure causes an increase in input air by the fans and vice versa. The average total fan power required also decreases with an increase in speed and wave amplitude as shown in Figs. 59 and 79.

The computer program assumes an initial gap at the stern seal of 25.52 square feet. An additional gap is calculated due to wave conditions. This additional gap will occur only when the wave surface is approximately below the level of the keel. The total gap at the stern is then based on the initial gap and any gap due to the wave. It was found that the area of the gap due to the wave had little or no effect on the total area of the gap at the stern. This was primarily due to the small amplitude waves used in the study.

From the results obtained of the input of air by the fans and the total fan power required, it shows that the more severe wave conditions require less input of air and

horsepower. The volume of the plenum was still being replenished by air about every 2.0 seconds.

B. WAVE CONDITIONS

Wave lengths of 72 feet (λ), both for ahead and astern waves, had the smallest effect on the performance of the 100-B SES. The amount of decrease in speed from the initial speed input to the steady-state speed was the smallest for a 72 foot wave length. In addition, the center of gravity acceleration and bow acceleration were less for the 72 foot wave length than either the 36 foot or 108 foot wave length. Generally the average stern seal leakage rate, total fan power, bow seal input of air, plenum input of air, stern seal input of air, and bow seal, stern seal, and plenum pressures were higher.

Although it is not known why this result did occur, it appears that a wave length approximately equal to the length of the craft gives the best performance of the craft in regard to minimum motion.

VI. CONCLUSIONS

A. PERFORMANCE

The performance of the SES 100-B, as determined by computer simulation, did not vary appreciably between ahead (directly on the bow) waves and astern (directly astern) waves under the same wave conditions. Steady-state speeds were larger, average plenum pressures were slightly higher, the fluctuation of pitch angle was larger, and the average draft was slightly less for astern waves as compared to ahead waves. The other performance variables shown in Figs. 41 through 80 were of similar values.

Under similar wave conditions, the computer program showed that the craft could proceed through larger amplitude astern waves than ahead waves. Table IV showed, for example, that a wave length of 36 feet and wave amplitude of 2 feet from astern could be run at a speed of 60 knots (vice only 50 knots if the wave was from ahead) before a negative fan power developed. The craft could run at a speed of 40 knots in an astern wave of wave length 36 feet and wave amplitude of 4 feet before an immersion depth greater than 6.6 feet occurred. At the same speed, a negative fan power condition developed for an ahead wave of wave length 36 feet and wave amplitude of 3 feet. Wave lengths and wave amplitudes in this range are associated with a state 2 to state 3 sea condition. Therefore, it

appears that the CAB concept, and particularly the SES 100-B, will be limited to calm or moderate sea conditions.

When bow and sidewall leakage did occur, generally the amount of leakage was larger at the slower speeds for a given wave condition. Table VI shows when bow and sidewall leakage did occur. Increasing the wave length resulted in larger leakage rates out the bow and sidewall. Under a given speed and wave condition, the magnitude of bow and/or sidewall leakage was larger for an astern wave than an ahead wave.

As speed was increased, in general the average values of pitch and draft increased with a corresponding decrease in their fluctuation values. The fluctuations of the center of gravity acceleration and bow acceleration also increased.

As speed was increased, in general the average values of bow seal, stern seal, and plenum pressures decreased with an increase in their fluctuation values. The average values of stern seal leakage also decreased, in general, with a corresponding increase in fluctuation as speed was increased. The average inputs of air by the fans to the bow seal, plenum, and stern seal decreased with a corresponding increase in fluctuation as speed was increased. The same trend also held for the average and fluctuation values of total fan power.

B. RECOMMENDATIONS

The following recommendations of additional areas of study are made on the basis of the results obtained during

this study.

1. Leakage Rates

The results of the computer program showed that the air is being replenished in the plenum every 1.5 to 2.0 seconds. From the CAB concept, this appears to be an excessive amount of air input required. It is recommended that the results of air leakage be compared against those of the SES 100-B to see if this is actually the case.

2. Air Inputs by Fans

The results of the computer program showed that an average decrease in air input by the fans and an average decrease in the amount of fan power occurred when a more severe wave condition was encountered. This does not appear feasible from the CAB concept. It is recommended that a study of the modeling of the air inputs by the fans and leakage rates be conducted to resolve this apparent discrepancy.

3. Stern Seal Leakage

The amount of stern seal leakage is based upon the total gap (both initial gap and gap due to waves) that is created at the stern seal. The amount of stern seal leakage is then dependent on the total gap and the plenum pressure that exists. It is recommended that the computer program be revised so that the amount of stern seal leakage is listed in two parts: leakage due to the initial gap and any additional leakage due to a gap being created by the waves.

4. Steady-State Speed

A minimum initial speed of 35 knots was used based on the results obtained in Fig. 2 and Appendix A. No computer runs were made to obtain the minimum critical speed between 30 and 35 knots under different wave conditions, both ahead and astern. It is recommended that an investigation into the minimum critical speed that can be used in the computer program be made to determine what effect different wave conditions will have on the values of this minimum critical speed.

5. Validity of Computer Data

Little or no performance data on the SES 100-B is available here at the Naval Postgraduate School. To check the validity of the computer data obtained in this study, a comparison of the performance data of the SES 100-B should be made under similar sea conditions as used in this study. A complete evaluation of the computer program for the selected variables that were studied could then be made.

6. Additional Data

The range of wave conditions was very limited in this study. Although basic trends could be developed, it is recommended that additional computer runs be made using simple waves from abeam and then using complex waves composed of 2 or more different waves. Realistic sea conditions should be modeled by the use of multiple simple waves as input data.

APPENDIX A

CALCULATION OF CRITICAL SPEED

From Newton's Second Law it is known that

$$F = ma \tag{3.1}$$

The longitudinal force, F_x, is equal to

$$F_x = \text{Thrust} - \text{drag} \tag{3.2}$$

Considering thrust as being constant, then we need only be concerned with those terms involving u to find the critical value of speed. Since u is composed of those terms that are u^2 and $u^{-1.56}$ dependent, Eq. (3.1) and Eq. (3.2) can be written as

$$m\dot{u} = -(k_1 u^2 + k_2 u^{-1.56}) + \text{Thrust} \tag{3.3}$$

Linearizing Eq. (3.3) by letting $u = u_o + \delta u$ gives

$$-m\,\delta\dot{u} = k_1(u_o{}^2 + 2u_o\delta u + \delta u^2)$$
$$+ k_2 u_o{}^{-1.56}\left(1 + \frac{\delta u}{u_o}\right)^{-1.56} - \text{Thrust} \tag{3.4}$$

Applying linear approximation, since we are interested in a steady-state critical speed for u_o, and by specifying

that $u_o^{-1.56} \cong u^{-3/2}$, Eq. (3.4) can be written as

$$-m\delta\dot{u} = (2k_1\ u_o)\ \delta u + k_2 u_o^{-3/2}\ (1 + \frac{\delta u}{u_o})^{-3/2} \qquad (3.5)$$

Letting $x = \frac{\delta u}{u_o}$, then

$$(1 + \frac{\delta u}{u_o})^{-3/2} = \frac{1}{(1 + x)^{3/2}} \qquad (3.6)$$

Noting that

$$\frac{1}{(1 + x)^{3/2}} = \frac{1}{[(1 + x)^2(1 + x)]^{1/2}} \qquad (3.7)$$

$$= \frac{1}{(1 + x)(1 + x)^{1/2}}$$

and that the value of x, which is equal to $\frac{\delta u}{u_o}$, will be much less than 1, Eq. (3.7) can then be written as

$$\frac{1}{(1 + x)(1 + x)^{1/2}} = \frac{1}{(1 + x)(1)} = 1 - x \qquad (3.8)$$

Thus Eq. (3.5) can be written as

$$-m\delta\dot{u} = (2k_1\ u_o)\ \delta u - k_2 u_o^{-5/2}\ \delta u$$

$$= [(2k_1 u_o) - k_2 u_o^{-5/2}]\ \delta u \qquad (3.9)$$

For $\delta\dot{u} = 0$, the critical speed, u_{oc}, is from Eq. (3.9)

$$2k_1 u_{oc} = k_2 u_{oc}^{-5/2} \tag{3.10}$$

Solving for u_{oc} gives

$$u_{oc} = \left(\frac{k_2}{2k_1}\right)^{2/7} \tag{3.11}$$

The values of k_1 and k_2 are determined from the calm water forces listed in Table III for 30 knots.

$$k_2 = \text{FXPWAV} = 5.898 \times 10^3$$

$$k_1 = \text{Total Forces} - \text{FXPWAV} = 3.867 \times 10^3$$

Converting k_1 and k_2 into feet per second gives

$$k_2 = \frac{5.898 \times 10^3}{(50.67)^{-3/2}}$$

$$k_1 = \frac{3.867 \times 10^3}{(50.67)^2}$$

where 50.67 feet/second = 30.0 knots.

Solving Eq. (3.11) for u_{oc} gives

$$u_{oc} \cong 51.5 \text{ feet per second} \cong 31.0 \text{ knots.}$$

APPENDIX B

SAMPLE INPUT DATA DECK

```
THE FOLLOWING IS A SAMPLE DATA DECK WITH EXPLANATION OF EACH CONTROL STATEMENT.

CONTROL STATEMENT 00101. VALUES IN FLOATING POINT FORMAT.
00101    0.0       60.0       .0001      1.0       0.0
BLANK 6-15 IS START TIME IN SECONDS (GENERALLY ZERO).
BLANK 16-25 IS FINISH TIME IN SECONDS.
BLANK 26-35 IS INITIAL INTEGRATION TIME STEP IN SECONDS.
BLANK 36-45 IS PRINT INTERVAL IN SECONDS.
BLANK 46-55 IS PRINT START TIME IN SECONDS.

CONTROL STATEMENT 00102. VALUES IN INTEGER FORMAT ON SECOND CARD.
00102
    1    1    1    1    1    1    1    1    1    1    1
BLANK 5 IS PRINT SWITCH FOR LATERAL ACCELERATION AND INTEGRATION TIME STEP.
BLANK 10 IS PRINT SWITCH FOR SUBROUTINE FAN.
BLANK 15 IS PRINT SWITCH FOR MAIN PROGRAM.
BLANK 20 IS PRINT SWITCH FOR SUBROUTINE SIDEWL.
BLANK 25 IS PRINT SWITCH FOR SUBROUTINE BOWSL.
BLANK 30 IS PRINT SWITCH FOR SUBROUTINE STNSL.
BLANK 35 IS PRINT SWITCH FOR SUBROUTINE WAVES.
BLANK 40 IS PRINT SWITCH FOR SUBROUTINE RUDDER.
BLANK 45 IS PRINT SWITCH FOR SUBROUTINE PROP.
BLANK 50 IS PRINT SWITCH FOR SUBROUTINE AEROD.
BLANK 55 IS PRINT SWITCH FOR SUBROUTINE RHS.

CONTROL STATEMENT 00103. SECOND CARD IN INTEGER FORMAT, THIRD AND FOURTH CARD IN
FLOATING POINT FORMAT.
00103
10
.0001     .0002     .000001   .0000001  .0001     .000001   .000000001.000000001
.0001     .0001
BLANK 1-10,11-20, AND SO FORTH THRU THE THIRD AND FOURTH CARDS SET THE TOLERANCE
VALUES CN INTEGRATORS 1 THRU 10.

CONTROL STATEMENT 00104. VALUES IN INTEGER FORMAT ON SECOND CARD.
00104
    1    1
BLANK 5 IS PRINT SWITCH FOR VERTICAL PLANE SUMMARY.
BLANK 10 IS PRINT SWITCH FOR LATERAL PLANE SUMMARY.
```

```
CONTROL STATEMENT 00105. VALUES IN FLOATING POINT FORMAT ON SECOND CARD.
00105
                              1.0
BLANK 6-15. A 1 INDICATES ONLY LATERAL PLANE MCTICN. A 0 (BLANK) INDICATES SIX
DEGREES OF FREEDOM EQUATIONS.
BLANK 16-25. A 1 INDICATES SURGE EQUATION NOT USED. A 0 (BLANK) INDICATES SURGE
VELOCITY ALLOWED TO VARY.
BLANK 26-35. A 1 INDICATES THRUST IS VARIED TO GIVE CONSTANT SPEED SPECIFIED.
A 0 (BLANK) INDICATES THRUST IS HELD CONSTANT.
SURGE VELOCITY ALLOWED TC VARY.
BLANK 26-35. A 1.0 INDICATES THRUST IS VARIED TO GIVE CONSTANT SPEED SPECIFIED.
A 0.0 (BLANK) INDICATES THRUST IS HELD CONSTANT.

CONTROL STATEMENT 00201. VALUES IN FLOATING POINT FORMAT.
00201209999.313    33.092     7.092 1073780.0 2769405.0 3635907.0 -99900.313
BLANK 6-15 IS TOTAL CRAFT WEIGHT IN POUNDS.
BLANK 16-25 IS LONGITUDINAL CENTER OF GRAVITY IN FEET FORWARD OF TRANSOM.
BLANK 26-35 IS VERTICAL CENTER OF GRAVITY IN FEET ABOVE KEEL.
BLANK 36-45 IS MASS MOMENT OF INERTIA ABOUT X-AXIS IN SLUG PER SQUARE FOOT.
BLANK 46-55 IS MASS MOMENT OF INERTIA ABOUT Y-AXIS IN SLUG PER SQUARE FOOT.
BLANK 56-65 IS MASS MOMENT OF INERTIA ABCUT Z-AXIS IN SLUG PER SQUARE FOOT.
BLANK 66-75 IS MASS MOMENT OF INERTIA ABOUT XZ-AXIS IN SLUG PER SQUARE FOOT.

CONTROL STATEMENT 00301. VALUES IN FLOATING POINT FORMAT.
00301     11.0      11.0       5.0        5.0        72.0
BLANK 6-15 IS NUMBER OF STATIONS CN PORT SIDEWALL.
BLANK 16-25 IS NUMBER OF STATIONS ON STARBORAD SIDEWALL.
BLANK 26-35 IS NUMBER OF STATIONS ON BOW SEAL.
BLANK 36-45 IS NUMBER OF STATIONS ON STERN SEAL.
BLANK 46-55 IS TOTAL CRAFT LENGTH IN FEET.

CONTROL STATEMENT 00401. VALUES IN FLOATING POINT FORMAT.
00401    15.54     60.0       .7         1.28       1.36
BLANK 6-15 IS Y DISTANCE FROM CENTERLINE TO SIDEWALL IN FEET.
BLANK 16-25 IS AVERAGE WETTED LENGTH OF SIDEWALL IN FEET.
BLANK 26-35 IS LEAKAGE ORIFICE COEFFICIENT OF SIDEWALL.
BLANK 36-45 IS CROSS-FLOW DRAG COEFFICIENT OF SIDEWALL.
BLANK 46-55 IS AVERAGE BEAM OF SIDEWALL IN FEET.

CONTROL STATEMENT 00402. VALUES IN FLOATING POINT FORMAT.
00402    30.       3.0        3.0        15.0       14.875      -1.5      .075
BLANK 6-15 IS APPENDAGE CANT ANGLE IN DEGREES (POSITIVE IS CANT INBOARD).
BLANK 16-25 IS APPENDAGE SPAN IN FEET.
BLANK 26-35 IS APPENDAGE CHORD IN FEET.
BLANK 36-45 IS X COORDINATE OF APPENDAGE CENTROID IN FEET FORWARD OF TRANSOM.
BLANK 46-55 IS Y DISTANCE FROM CENTERLINE TO CENTROID OF APPENDAGE IN FEET.
BLANK 56-65 IS Z COORDINATE OF APPENDAGE CENTROID IN FEET ABOVE KEEL.
BLANK 66-75 IS AVERAGE THICKNESS RATIO OF APPENDAGE SECTION.
```

```
CONTROL STATEMENT 00501. VALUES IN FLOATING POINT FORMAT.
00501 7.5       5.479     25.52     .90       55.5      26.       9.101
BLANK 6-15 IS X COORDINATE OF STERN SEAL HINGE IN FEET FORWARD OF TRANSOM.
BLANK 16-25 IS Z COORDINATE OF STERN SEAL HINGE IN FEET ABOVE KEEL.
BLANK 26-35 IS BASE LEAKAGE AREA IN SQUARE FEET.
BLANK 46-55 IS ANGLE BETWEEN LEADING EDGE OF SEAL AND CRAFT VERTICAL IN DEGREES.
BLANK 56-65 IS PRESSURE DIFFERENTIAL BETWEEN STERN SEAL BAG AND BUBBLE IN PSF.
BLANK 66-75 IS LENGTH OF LEADING EDGE OF STERN SEAL IN FEET.

CONTROL STATEMENT 00601. VALUES IN FLOATING POINT FORMAT.
00601 53.07     .60       24.       3.75
BLANK 6-15 IS X COORDINATE OF BOW SEAL HINGE IN FEET FORWARD OF TRANSOM.
BLANK 16-25 IS BOW LEAKAGE ORIFICE COEFFICIENT.
BLANK 26-35 IS PRESSURE DIFFERENTIAL BETWEEN BOW SEAL BAG AND BUBBLE IN PSF.
BLANK 36-45 IS HEIGHT OF BOW SEAL HINGE ABOVE KEEL IN FEET.

CONTROL STATEMENT 00701. VALUES IN FLOATING POINT FORMAT.
00701 65.31     31.16               28.00     65.31     33.4      6.17
BLANK 6-15 IS PLENUM LENGTH AT WATER SURFACE IN FEET.
BLANK 16-25 IS PLENUM WIDTH AT WATER SURFACE IN FEET.
BLANK 26-35 IS NOT USED.
BLANK 36-45 IS PLENUM WIDTH AT DECK IN FEET.
BLANK 46-55 IS PLENUM LENGTH AT DECK IN FEET.
BLANK 56-65 IS X COORDINATE OF CENTER OF PRESSURE IN FEET FORWARD OF TRANSOM.
BLANK 66-75 IS PLENUM AVERAGE HEIGHT.

CONTROL STATEMENT 00702. VALUE IN FLOATING POINT FORMAT.
00702     .6
BLANK 6-15 IS FROUDE NUMBER CORRESPONDING TO HUMP SPEED.

CONTROL STATEMENT 00801. VALUES IN FLOATING POINT FORMAT.
00801     -1.0      15.75     0.9       5091.4    3960.0
BLANK 6-15 IS X COORDINATE OF PROPELLER CENTER IN FEET FORWARD OF TRANSOM.
BLANK 16-25 IS Y DISTANCE FROM CENTERLINE TO PROPELLER CENTER IN FEET.
BLANK 26-35 IS Z COORDINATE OF PROPELLER IN FEET ABOVE KEEL.
BLANK 36-45 IS THRUST OF ONE PORPELLER IN POUNDS. VALUE DETERMINED FROM INITIAL
CONDITION.
BLANK 46-55 IS SIDE THRUST OF ONE PROPELLER IN POUNDS. VALUE CAN BE ZERO WHEN
TWO ENGINES ARE ONLY USED (NO ENGINE OUT).

CONTROL STATEMENT 00802. VALUE IN FLOATING POINT FORMAT.
00802
BLANK 6-15 IS TIME OF ENGINE OUT IN SECONDS. WAS NOT USED DURING THIS STUDY.
```

```
CONTROL STATEMENT 00901. VALUES IN FLOATING POINT FORMAT.
00901  6.125     15.6      -1.5       3.0       1.4       6.375      .108
BLANK 6-15 IS X COORDINATE OF CENTROID OF RUDDER IN FEET FORWARD OF TRANSOM.
BLANK 16-25 IS Y DISTANCE FROM CENTERLINE TO RUDDER CENTROID IN FEET.
BLANK 26-35 IS Z COORDINATE OF CENTROID OF RUDDER IN FEET ABOVE KEEL.
BLANK 36-45 IS RUDDER SPAN IN FEET.
BLANK 46-55 IS RUDDER ASPECT RATIO.
BLANK 56-65 IS RUDDER AREA IN SQUARE FEET.
BLANK 66-75 IS AVERAGE THICKNESS RATIO OF RUDDER SECTION.

CONTROL STATEMENT 00902. VALUES IN FLOATING POINT FORMAT.
00902
BLANK 6-15 IS INITIAL RUDDER DEFLECTION ANGLE IN DEGREES.
BLANK 16-25 IS STARTING TIME FOR RUDDER MOTION IN SECONDS.
BLANK 26-35 IS FINAL RUDDER ANGLE IN DEGREES.
BLANK 36-45 IS RUDDER DEFLECTION RATE IN DEGREES PER SECOND.
BLANK 46-55 IS TIME FOR STARTING OF RUDDER REVERSE IN SECONDS.
THIS STATEMENT WAS NOT USED DURING STUDY.

CONTROL STATEMENT 01001. VALUES IN FLOATING POINT FORMAT.
01001     63.15     31.65
BLANK 6-15 IS REFERENCE LENGTH IN FEET.
BLANK 16-25 IS REFERENCE WIDTH IN FEET.

CONTROL STATEMENT 01102. VALUES IN FLOATING POINT FORMAT.
01102     1.0       180.0
     0.0       0.0
BLANK 6-15 IS NUMBER OF WAVE COMPONENTS.
BLANK 16-25 IS INITIAL HEADING IN DEGREES (180 DEGREES EQUALS HEAD SEAS).
BLANK 1-10 ON SECOND CARD IS WAVE LENGTH IN FEET.
BLANK 11-20 ON SECOND CARD IS WAVE AMPLITUDE IN FEET.

CONTROL STATEMENT 01201. VALUES IN FLOATING POINT FORMAT.
01201     40.0      0.23      15.26     92.8
BLANK 6-15 IS INITIAL SPEED IN KNOTS.
BLANK 16-25 IS INITIAL PITCH ANGLE IN DEGREES (POSITIVE IS BOW UP).
BLANK 26-35 IS INITIAL DRAFT AT CENTER OF GRAVITY IN INCHES.
BLANK 36-45 IS INITIAL BUBBLE PRESSURE IN PSF.

CONTROL STATEMENT 01300. THIS CARD USED TO SIGNAL END OF DATA FOR GIVEN CASE.
013

CONTROL STATEMENT 01400. THIS CARD USED TO SIGNAL END OF RUN.
014
```

```
CONTROL STATEMENT 01500. VALUES IN FLOATING POINT FORMAT.
THIS CONTROL STATEMENT WAS NOT USED IN THIS STUDY SINCE STATEMENT IS CONCERNED
WITH SHEAR AND MOMENT PROGRAM DATA.

CONTROL STATEMENT 01800. THIS CARD IS USED TO PRINT ALPHANUMERIC DATA.
018
    TEST CASE 1 CALM WATER SPEED 40 KNOTS

CONTROL STATEMENT 01901. VALUES IN FLOATING POINT FORMAT.
01901 1.         1700.      17.        1.         1700.
 0.        33.        62.        87.        106.       118.       128.       133.
 137.      139.       141.       143.       146.       152.       160.       180.
 200.
1185.      1100.      1000.      900.       800.       700.       600.       500.
 400.      300.       100.       -50.       -95.       -145.      -175.      -220.
 -235.
BLANK 6-15 OF FIRST CARD IS NUMBER OF BOW SEAL FANS.
BLANK 16-25 OF FIRST CARD IS SPEED OF BOW SEAL FANS IN RPM.
BLANK 26-35 OF FIRST CARD IS NUMBER OF DATA POINTS (MAXIMUM OF 25).
SECOND AND SUBSEQUENT CARDS ARE TABULAR VALUES OF FAN PRESSURE DIFFERENTIAL IN
PSF AND CORRESPONDING VOLUMETRIC FLOW RATE IN CUBIC FEET PER SECOND.

CONTROL STATEMENT 01902. VALUES IN FLOATING POINT FORMAT.
01902 5.         1700.      16.        1.         1700.
 0.        28.        54.        76.        91.        104.       112.       118.
 120.      121.       122.       126.       133.       142.       160.       176.
 1195.     1100.      1000.      900.       800.       700.       600.       500.
 400.      0.         -50.       -100.      -150.      -180.      -220.      -240.
BLANK 6-15 OF FIRST CARD IS NUMBER OF CUSHION FANS.
BLANK 16-25 OF FIRST CARD IS SPEED OF CUSHION FANS IN RPM.
BLANK 26-35 OF FIRST CARD IS NUMBER OF DATA POINTS (MAXIMUM OF 25),
SECOND AND SUBSEQUENT CARDS ARE TABULAR VALUES OF FAN PRESSURE DIFFERENTIAL IN
PSF AND CORRESPONDING VOLUMETRIC FLOW RATE IN CUBIC FEET PER SECOND.

CONTROL STATEMENT 01903. VALUES IN FLOATING POINT FORMAT.
01903 2.         1870.      17.        1.         1870.
 0.        9.         42.        70.        94.        114.       127.       136.
 144.      147.       150.       151.       154.       160.       180.       200.
 218.
 1340.     1300.      1200.      1100.      1000.      900.       800.       700.
 600.      500.       400.       0.         -100.      -165.      -215.      -245.
 -260.
BLANK 6-15 OF FIRST CARD IS NUMBER OF STERN SEAL FANS.
BLANK 16-25 OF FIRST CARD IS SPEED OF STERN SEAL FANS IN RPM.
BLANK 26-35 OF FIRST CARD IS NUMBER OF DATA POINTS (MAXIMUM OF 25).
SECOND AND SUBSEQUENT CARDS ARE TABULAR VALUES OF FAN PRESSURE DIFFERENTIAL IN
PSF AND CORRESPONDING VOLUMETRIC RATE IN CUBIC FEET PER SECOND.
```

APPENDIX C

NODAL METHOD FOR WEIGHT DISTRIBUTION

```
CONTROL STATEMENT 00202 IS USED WHEN DISCRETE MASS DISTRIBUTION IS DESIRED.
THE FIRST CARD CONTAINS CONTROL STATEMENT 00202.
THE SECOND THRU SUBSEQUENT CARDS CONTAIN WEIGHT AND CENTER OF GRAVITY.
COLUMN 1-10 LISTS DISCRETE WEIGHT IN POUNDS.
COLUMN 11-20 GIVES LONGITUDINAL C. OF G. IN FEET FORWARD OF TRANSOM.
COLUMN 21-30 GIVES TRANSVERSE C. OF G. IN FEET TC STARBOARD.
COLUMN 31-40 GIVES VERTICAL C. OF G. IN FEET ABOVE KEEL (BASELINE).
THE LAST CARD MUST CONTAIN A -1.0 IN COLUMN 1-10.
THE FOLLOWING IS THE BASIC INPUT DATA FOR CONTROL STATEMENT 00202 FOR THE 100-B.

00202
    269.11     71.17      1.00      6.17          B-100T-NODES   1,  1
    600.00     71.17      6.00      6.17          B-100T-NODES   3, 13
    212.74     71.17      6.00     13.50          B-100T-NODES   6, 10
    103.09     71.17      1.00     13.50          B-100T-NODES   8,  8
    851.74     65.00      1.00      6.17          B-100T-NODES  16, 16
   1281.47     65.00      6.00      6.17          B-100T-NODES  18, 32
    993.44     65.00     14.00      6.17          B-100T-NODES  20, 30
    376.06     65.00     14.00     13.50          B-100T-NODES  21, 29
    759.07     65.00      6.00     13.50          B-100T-NODES  23, 27
    616.99     65.00      1.00     13.50          B-100T-NODES  25, 25
   1148.26     60.00      1.00      6.17          B-100T-NODES  35, 35
   1938.99     60.00      6.00      6.17          B-100T-NODES  37, 33
   1231.27     60.00     14.00      6.17          B-100T-NODES  39, 30
    174.90     60.00     15.75      0.00          B-100T-NODES  40, 56
    284.17     60.00     17.50      1.00          B-100T-NODES  41, 55
    528.57     60.00     17.50      6.17          B-100T-NODES  42, 54
    272.20     60.00     17.50     13.50          B-100T-NODES  43, 53
    988.80     60.00     14.00     13.50          B-100T-NODES  44, 52
   1500.00     60.00      6.00     13.50          B-100T-NODES  46, 50
    928.96     60.00      1.00     13.50          B-100T-NODES  48, 48
    706.95     44.00      1.00      6.17          B-100T-NODES  89, 89
   1491.89     44.00      6.00      6.17          B-100T-NODES  91, 87
   1803.47     44.00     14.00      6.17          B-100T-NODES  93, 85
    479.54     44.00     15.75      0.00          B-100T-NODES  94,110
    772.97     44.00     17.50      1.00          B-100T-NODES  95,109
    882.24     44.00     17.50      6.17          B-100T-NODES  96,108
    384.56     44.00     17.50     13.50          B-100T-NODES  97,107
   1287.64     44.00     14.00     13.50          B-100T-NODES  98,106
   1382.62     44.00      6.00     13.50          B-100T-NODES 100,104
    758.30     44.00      1.00     13.50          B-100T-NODES 102,102
    501.93     23.50      1.00      6.17          B-100T-NODES 143,143
```

990.35	23.50	6.00	6.17	B-100T-NODES 145,141
1392.66	23.50	14.00	6.17	B-100T-NODES 147,139
434.36	23.50	15.75	0.00	B-100T-NODES 148,138
686.49	23.50	17.50	1.00	B-100T-NODES 149,137
792.66	23.50	17.50	6.17	B-100T-NODES 150,166
345.17	23.50	17.50	13.50	B-100T-NODES 151,165
989.96	23.50	14.00	13.50	B-100T-NODES 154,162
1603.86	23.50	6.00	13.50	B-100T-NODES 156,160
1386.10	23.50	1.00	13.50	B-100T-NODES 158,158
366.02	14.50	1.00	6.17	B-100T-NODES 174,174
783.01	14.50	6.00	6.17	B-100T-NODES 176,172
1205.40	14.50	14.00	6.17	B-100T-NODES 178,170
389.96	14.50	15.75	0.00	B-100T-NODES 179,169
633.59	14.50	17.50	1.00	B-100T-NODES 180,168
572.97	14.50	17.50	6.17	B-100T-NODES 181,167
355.98	14.50	17.50	13.50	B-100T-NODES 182,196
948.26	14.50	14.00	13.50	B-100T-NODES 185,193
1295.37	14.50	6.00	13.50	B-100T-NODES 187,191
866.02	14.50	1.00	13.50	B-100T-NODES 189,189
388.80	7.50	1.00	6.17	B-100T-NODES 205,205
1122.01	7.50	6.00	6.17	B-100T-NODES 207,203
1523.16	7.50	14.00	6.17	B-100T-NODES 209,201
450.58	7.50	15.75	0.00	B-100T-NODES 210,200
672.59	7.50	17.50	1.00	B-100T-NODES 211,199
518.15	7.50	17.50	6.17	B-100T-NODES 212,198
379.15	7.50	17.50	13.50	B-100T-NODES 213,197
1316.99	7.50	14.00	13.50	B-100T-NODES 216,224
1211.97	7.50	6.00	13.50	B-100T-NODES 218,222
508.88	7.50	1.00	13.50	B-100T-NODES 220,220
261.78	0.00	1.00	6.17	B-100T-NODES 236,236
941.70	0.00	14.00	6.17	B-100T-NODES 240,232
1063.32	0.00	15.75	0.00	B-100T-NODES 241,231
705.79	0.00	6.00	6.17	B-100T-NODES 238,234
1513.13	0.00	17.50	1.00	B-100T-NODES 242,230
367.18	0.00	17.50	6.17	B-100T-NODES 243,229
187.26	0.00	17.50	13.50	B-100T-NODES 244,228
777.99	0.00	14.00	13.50	B-100T-NODES 247,255
678.76	0.00	6.00	13.50	B-100T-NODES 249,253
230.50	0.00	1.00	13.50	B-100T-NODES 251,251
4230.	38.88	7.5	7.5	CARGO BAGS I,IV, FWD
4230.	38.88	2.5	7.5	CARGO BAGS II,IIIFWD
4230.	29.0	2.5	7.5	CARGO BAGS I,II, AFT
4290.2	62.47	2.9	9.92	SERVICE TANK %& BAL<
3800.	62.13	12.45	9.22	BALLAST FWD.
3800.	10.98	15.73	3.38	BALLAST AFT
6000.	47.84	16.17	3.59	MAIN TANKS T1 & T8
9050.	28.58	16.03	3.72	MAIN TANKS T3 & T6
9000.	18.88	15.88	3.56	MAIN TANKS T4 & T5

LIST OF REFERENCES

1. Navy Times, p. 36, 28 March 1973.

2. Surface Effect Ships Project Office Letter PM 1722:SD:et to Professor George J. Thaler, 7 December 1972.

3. Oceanics Inc. Report 71-84A, Equations of Motion of SES Craft with Six Degrees of Freedom, Part I, by P. Kaplan, J. Bentson, and T.P. Sargent, August 1971.

4. Oceanics Inc. Report 71-85, SES Motions and Loads Program Users Manual, by J. Bentson, T.P. Sargent, and A.J. Raff, August 1971.

5. Bell Aerospace Report 7308-947009, SES-100B, p. 3-17b, 9 October 1972.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Professor George J. Thaler, Code 52 Tr Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	5
4.	Assoc. Professor Alex Gerba, Jr., Code 52 Gz Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	1
5.	Assoc. Professor Milton L. Wilcox, Code 52 Wx Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	1
6.	CDR A. Skolnik, USN Surface Effect Ships Project Office P.O. Box 34401 Washington, D.C. 20034	1
7.	Mr. Sid Davis, Code PM-17 Department of the Navy Surface Effect Ships Project Office P.O. Box 34401 Washington, D.C. 20034	1
8.	Mr. James E. Blalock Department of the Navy Naval Ship Research and Development Center Carderock, Laboratory Bethesda, Maryland 20034	1
9.	Mr. Arnold W. Anderson, Code 1731A.1 Department of the Navy Surface Effect Ships Project Office, PM-17 Bethesda, Maryland 20034	1

10. Assoc. Professor D. M. Layton, 1
Code 57 Ln
Department of Aeronautical Engineering
Naval Postgraduate School
Monterey, California 93940

11. LCDR Lonnie F. Cagle, USN 1
P. O. Box 96
Dixon, California 95620

12. LT. Kenneth R. Myers, USN 1
226 Solway Court
Timonium, Maryland 21093

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

ORIGINATING ACTIVITY (Corporate author) Naval Postgraduate School Monterey, California 93940	2a. REPORT SECURITY CLASSIFICATION Unclassified
	2b. GROUP

REPORT TITLE

Some Performance Characteristics of the Bell 100 Ton Surface Effect Ship

DESCRIPTIVE NOTES (Type of report and, inclusive dates)

Master's Thesis; June 1973

AUTHOR(S) (First name, middle initial, last name)

Lonnie Francis Cagle

REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 1973	151	5

CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
PROJECT NO.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Postgraduate School Monterey, California 93940

ABSTRACT

A computer program for simulating the performance of the 100-B Surface Effect Ship is used to study the longitudinal motions of the ship under various wave conditions. An investigation into the effect that waves have on bow seal, stern seal, and plenum pressures is conducted. The relationship between the different pressures and their associated requirements of input air from the fans is studied. It is concluded that the computer program is limited to a certain range of speeds. The concept of the ship capturing air to reduce drag and increase its speed is questionable due to the rapid replenishment of air required to keep the ship riding on its bubble of air.

Security Classification

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Surface Effect Ship						
Captured Air Bubble						
Air Cushion Vehicle						

DD FORM 1 NOV 65 1473 (BACK)
S/N 0101-807-6821

Security Classification

A-31409

Thesis 145008
C17 Cagle
c.1 Some performance characteristics of the Bell 100 ton surface effect ship.